Cranfield University

School of Industrial and Manufacturing Science

Enterprise Integration

DOCTOR OF PHILOSOPHY

2004

PETROS SOUCHOROUKOV

IMPROVEMENT OF COST ESTIMATING INTERNAL PRACTICE

Supervisor: Dr. Rajkumar Roy

October 2004

THIS THESIS IS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

THIS PAGE IS INTENTIONALLY LEFT BLANK

Abstract

This thesis is concerned with understanding the internal costing practices employed by commercial and engineering disciplines of cost estimating for generating estimates at the conceptual design stage of complex hardware products. It examines whether there is a formal structure in the interaction between the two groups that can be represented within a model. The aim is to develop a framework that will formalise and improve the communication of commercial and engineering disciplines in cost estimating.

A literature review examines the role of different costing techniques and the information requirements for generating cost estimates. The review identifies that there is a lack of research in the information requirements for cost estimating of specific manufacturing industries, and that the interaction of commercial and engineering disciplines of cost estimating at conceptual design stage is hindered by the different focuses of these groups.

By conducting a survey study the author identifies the internal practice in cost estimating for the automotive industry. The survey establishes that in order to improve the internal practice it is essential to establish a data infrastructure that formalises and enables the reuse of the cost estimates and improves the interaction between the two groups. The author identifies a common cost estimating process for the automotive industry. This study establishes the required data and information elements and information sources that need to be collected in order to have reliable data infrastructure. Using a case study approach, the author also establishes that it is essential to analyse the product functions in such a way that will enable the development of a detailed cost estimating model at the conceptual design stage, which will improve interaction between the commercial and engineering groups. The function-based cost estimating process becomes the focus of detailed studies using experts from the automotive industry. This results in a generic framework that provides a formalised structure to represent functional requirements in the form of a detailed cost estimating model.

The thesis concludes that product functions need to be captured and analysed during the conceptual development of a product and be associated to cost estimates. The developed results provide both groups of cost estimating a structured, consistent approach to developing cost estimates at the conceptual design stage. The data infrastructure and the function-based cost estimating framework is validated through case studies and expert evaluation. The approach contributes towards improvement of the internal cost estimating practice with the automotive industry.

THIS PAGE IS INTENTIONALLY LEFT BLANK

Acknowledgements

I would like to thank Dr. Rajkumar Roy for his support and guidance throughout my studies at Cranfield University. His support was crucial to my starting, and completing this research. The last four years have been the most challenging of my life and it is an experience I will never forget.

I would like to thank the staff of the Department of Enterprise Integration for providing an excellent working environment. In particular I would like to thank Mrs. Linda Willsher for her always friendly and helpful assistance.

I would like to acknowledge all the sponsors of the project for their continued support. I would like to thank Terry Griggs, for his encouragement, support, and genuine interest throughout the research. To Gareth Jones for his help with data collection and interpretation. And to Bill Ewin, for providing answers to my every question.

Finally, I would like to thank my fiancée, Tina, for her love and support during my work in this research. I would also like to thank my mother for her support in getting me this far, and for always encouraging me along the way.

THIS PAGE IS INTENTIONALLY LEFT BLANK

List of Publications

Roy, R. Souchoroukov, P. and Koponen, H. (2003). Information Requirements for Cost Estimating and the Automotive Industry. In: *8th Annual ASME Design for Manufacturing Conference*, Chicago, Illinois September 2-6 2003, Paper Reference: DETC2003/DFM-48153.

Souchoroukov, P. Roy, R. and Mishra, K. (2003). Using Functional Decomposition Techniques for Cost Estimating at the Conceptual Design Stage. In: *ISPA-SCEA 4th Co-Sponsored Int. Conference,* Orlando, Florida, USA, June 17-20 2003, CD-Rom Proceedings, ISBN: 0-9720204-4-4.

Souchoroukov P., Roy R., and Mishra K. (2002). Data and Information in Cost Estimating. *In CD-Rom Proceedings of 13th Conference of SCEA (the Society of Cost Estimating & Analysis),* Scottsdale, Arizona, June 11-14, 2002. pp. 44-45.

Mishra, K., Roy, R., Souchoroukov, P. and Taratoukhine, V. (2002), Knowledge in the Commercial and Engineering Activities within Cost Estimating. In: *9th ISPE International Conference on Concurrent Engineering: Research and Applications,* Cranfield University, July 28–31 2002, A.A. Balkema Publishers, Netherlands, pp. 545-554.

Mishra, K., Roy, R., and Souchoroukov, P. (2002). Knowledge Reuse: CE2 - Focused Training. In: *Proceedings of International Conference on Practical Aspects of Knowledge Management PAKM,* Vienna, Austria, December 2-3, 2002, pp. 595–612.

Roy, R., Souchoroukov, P., Mishra, K, (2001). Interface between Commercial and Engineering Activities in Cost Estimating: Industry Practice. In: *Proceedings of the Third Joint Annual ISPA / SCEA International Conference*, Toronto, Canada 12-15 June 2001, pp.143-147.

THIS PAGE IS INTENTIONALLY LEFT BLANK

List of Contents

THIS PAGE IS INTENTIONALLY LEFT BLANK

List of Figures

THIS PAGE IS INTENTIONALLY LEFT BLANK

List of Tables

THIS PAGE IS INTENTIONALLY LEFT BLANK

List of Acronyms

CE	Cost Estimating
CE-C	Cost estimators with Commercial Background
CE-E	Cost estimators with Engineering Background
CER	Cost Estimating Relationship
EJ	Expert Judgement
EPSRC	Engineering and Physical Sciences Research Council
FBC	Feature Based Costing
FUCE	Function-based Cost Estimating
IPT	Integrated Product Team
VA	Value Analysis
VE	Value Engineering
OEM	Original Equipment Manufacturer
PBS	Product Breakdown Structure
QAF	Quotation Analysis Form
QFD	Quality Function Deployment
WBS	Work Breakdown Structure
X-Pat	eXpert Process Knowledge Analysis Tool

THIS PAGE IS INTENTIONALLY LEFT BLANK

1. Introduction

The purpose of this chapter is to provide a foreword to the thesis by introducing the research topic. The context of the research will be described and the problem statement will be presented. The importance of improving the internal cost estimating practices between the disciplines of Cost Estimating (CE) will be established.

Following the description of the problem under investigation, the specific aim of the research will be identified. Consideration will then be given to the scope of the research. Finally the structure of the thesis will be described in order to provide the reader with a general overview.

1.1. Research Background

This thesis is concerned with understanding the role and utilisation of commercial and engineering disciplines of cost estimating for generating estimates at the conceptual design stage of complex hardware products. Cost Engineering and Cost Estimating are terminologies used in industries. Cost Engineering is an embracing term that includes Cost Estimation.

Who is a Cost Engineer? The Association for the advancement of Cost Engineers (AACE) defines a cost engineer as "an engineer whose judgement and experience is utilised in the application of scientific principles and techniques to the problems of cost estimation, cost control, and profitability" (AACE, 2000).

What is Cost Estimation? Again the AACE defines it as "The determination of quantity and the predicting or forecasting, within a defined scope, of the cost required to construct and equip a facility, to manufacture goods, or to furnish a service. Costs are determined utilising experience and calculating and forecasting the future cost of resources, methods and management within a scheduled time frame. Included in these costs are assessment and an evaluation of risks and opportunities. Cost estimation provides a basis for feasibility studies, business planning, budget preparation, and cost and scheduling control" (AACE, 2000).

Cost estimating has a tremendous impact on world and national economics and, hence, on individuals, societies, and living standards. This is often not understood or tends to be misjudged. For example, virtually all "go or no-go" decisions on projects, whether they be £100,000 or £10 billion are made on the basis of economics, which in turn relies on the availability and accuracy of a cost estimate. This applies to both private industry and government. National budgets themselves are nothing more than a compilation of smaller budgets or estimates for operating costs and capital expenditures.

Because estimating or predicting cost is an essential part of any project and therefore any industry, cost estimating is not confined to any particular industry or group of industries and has applications throughout the business world and, for that matter, the domestic world.

Enterprises involved mainly in manufacturing hardware products (Car manufacturers, Aerospace industries, etc.) perform cost estimating throughout the life cycle of a product. Estimators can be broadly categorised into two groups, Cost estimators with commercial background (CE-C) Cost Estimators with Engineering background (CE-E).

> The purpose of **CE-C** is to provide key business information for decision-making in a top-down fashion. Their costing activities try to evaluate, and optimise (fit) a combination of requirements (customer and business) with potential or selected solution(s), across a wide range of business processes, with cost as the common denominator.

The process and organisations covered by CE-C in costing are for example engineering, testing, tooling, manufacturing, procurement, logistic support, and management. During the development of a new product CE-C will be mainly involved at the early stages of a product (figure 1-1). They are responsible, together with other commercial disciplines to interact with the customer, identify their requirements and produce the costs that they will have to be agreed in a contract/project. CE-C also have to follow standard costing and accounting methods (e.g. Questionnaire on the Method of Allocation of Costs (QMAC)) depending on customer requirements, and comply to post contract work management and control methods like EVMS (Earned Value Management Systems). They also need to be fully aware of UK & customer government legislative regulations, which affect costs and change the amount of risk carried in a specific project.

> The **CE-E** try to model the design to manufacturing cost in a bottom-up approach for establishing relative costs for different solutions, and methods.

CE-E need to have detailed knowledge about the product, the manufacturing process, and manufacturing capability of the organisation. But, unlike commercial estimating, CE-E are focused on design, manufacturing, and tooling activities only. Due to the above, their involvement largely starts at the manufacturing stage (figure 1-1).

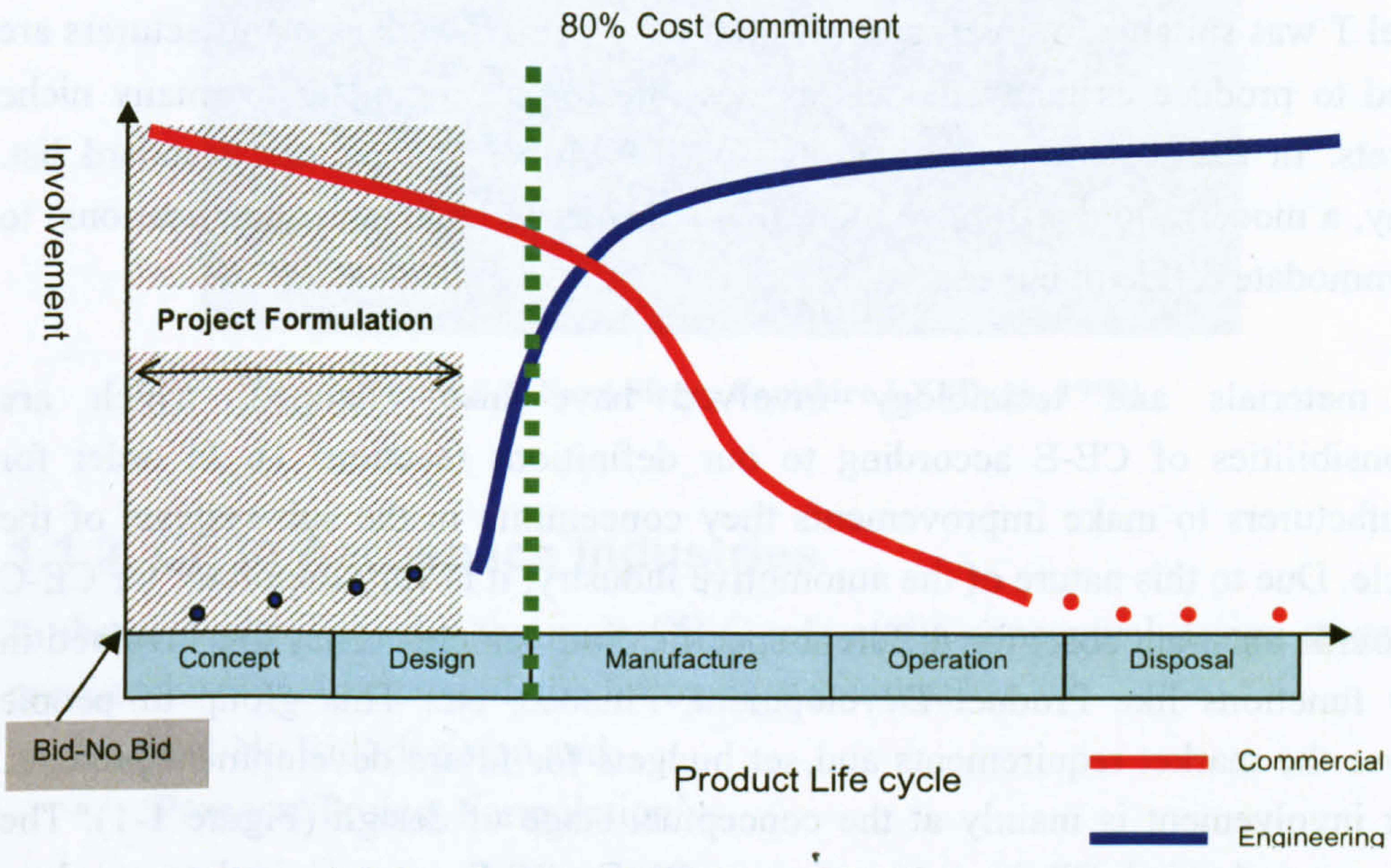


Figure 1-1: Involvement of CE-C and CE-E in the product life cycle

CE internal practice very much depends on the interaction between CE-E and CE-C. This research aims to improve cost estimating internal practice by improving the interaction between the two groups of cost estimating.

1.1.1. Cost Estimating in Automotive Industry

In the automotive industry the product has not changed significantly since the Model 'T' Ford of 1907 (Figure 1-2). Model 'T' Ford incorporated the following features:

- A body with windows and doors;
- Four seats and steering wheel at the front;
- Four wheels, one at each corner;
- An engine, at the front, with rear-wheel drive and brakes all round;
- Front and rear lights;
- Balloon tyres;

- Front and rear bumpers.

After 75 years the company produced the Sierra model (Figure 1-3). In other words the car has not changed conceptually and still uses the same principles.

What has changed though in the last decade are the market demands. In the past, model T was suitable for everyone who wanted a car. Nowadays manufacturers are forced to produce as many models as possible to accommodate for many niche markets. In the past the specifications for the Model T were one standard list. Today, a modern Ford will have more that a dozen variants (and specifications) to accommodate different buyers.

The materials and technology involved have also changed, which are responsibilities of CE-E according to our definitions (section1.1). In order for manufacturers to make improvements they concentrate in the sub-systems of the vehicle. Due to this nature of the automotive industry, it is very important for CE-C to provide accurate costs for different specification vehicles. They are involved in other functions like Product Development, Finance, etc. This group of people analyse the market requirements and set budgets for future development projects. Their involvement is mainly at the conceptual stage of design (Figure 1-1). The main group behind CE in automotive is CE-E. CE-E are required to produce detailed cost estimates throughout the product lifecycle. Their main involvement comes at the production stage of the vehicle. The lack of good interaction, as we are going to see in this research, leads to communication problems.

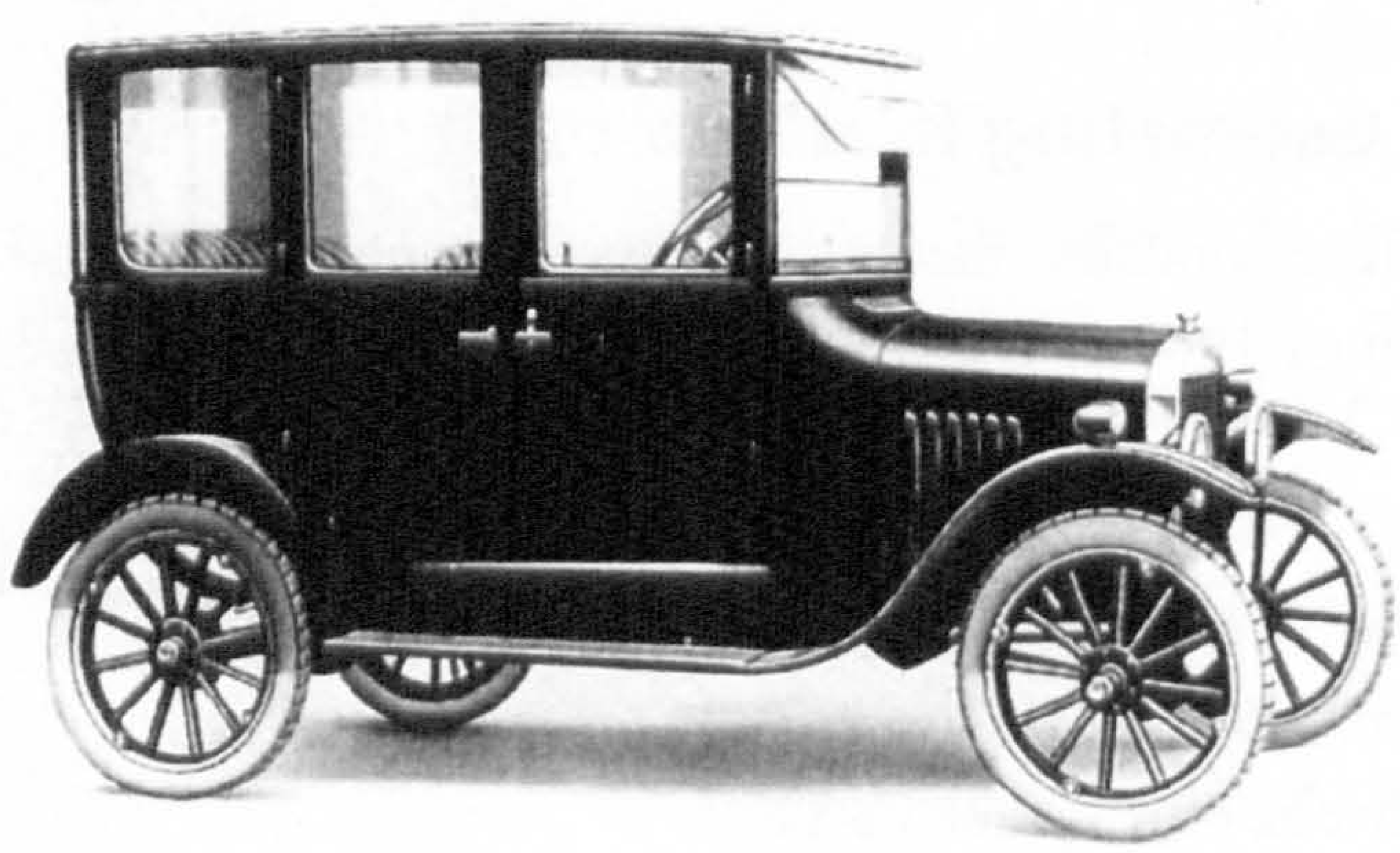


Figure 1-2: Model 'T' Ford of 1907 (Pugh, 1990)

Figure 1-3: Ford Sierra Sapphire LX (Pugh, 1990)

1.1.2. CE in Aerospace Industries

In the aerospace industry the main CE-C role at the conceptual design stage is to provide the organisation with the following activities:

- 'Bid-No Bid' decision and;
- 'Proposal/Project Formulation'.

'Bid-no Bid' decision is the stage where the organisation contemplates if it is interested in a specific customer's request (Figure 1-1). CE-C investigate what are the requirements of the customer and what are the functions required to be performed by the product. The estimator identifies similar products built in the past, if any, and using parametric models (section 2.2.3) and standard accounting practices, he decides if the product is economically viable for the organisation. By using parametric models estimators can produce estimates faster and therefore respond to the market's demands.

The 'Project Formulation' stage begins once the organisation has decided to bid for a contract and needs to put forward a detailed proposal. The CE-C role is to provide as accurate cost as possible. The main tools available to them are parametric tools like PRICE-H (Price Systems, 2004), SEER-H (Galorath, 2004), etc. Although the costs produced by these tools are quite accurate, they do not breakdown cost elements in detail with regards to the manufacturing phase.

Another issue is the complexity of aerospace products, especially in the military. It is not possible for a person with a commercial background to know what it takes to make a highly advanced aerostructure, and indeed it is not his job function. Furthermore, a system can take 20 years to be developed from concept. In that time the requirements can very likely change. For that reason CE-C interact with all the groups of the organisation that are involved in the project and ask them to develop detailed costs for their specific work activities. CE-Es are within these groups. They try to produce cost estimates using detailed, bottom up estimates as defined above.

1.1.3. Research Context

The above discussion raises a number of issues in the relationship of CE-C and CE-E.

- Changes in the specifications of a product during negotiations do not cascade from CE-C to CE-E. A change thought insignificant to a commercial person can have a significant impact on the designing of the product thus affecting the cost engineer's task and vice versa.
- A certain understanding and knowledge of the product and its cost implications exists between CE-C and CE-E. When people leave a company or retire, the link between commercial and engineering groups, with regards the assumptions made to the product costing, is lost. This is an important issue since there is no standard process for linking the commercial and engineering requirements of cost estimating.
- It is difficult for the rest of the organisation to understand a final cost estimate. This limits the benefits that can be acquired using cost estimates within the organisation and in negotiations with a customer.
- Commercial people involved in costing do not necessarily have engineering background. Nonetheless they are the primary force for decision making within a company for cost related issues and when it comes to negotiating with a customer or supplier, their participation is very important. When this involves technology intensive products, the lack of engineering knowledge can hinder the role of cost estimating.
- Engineering people on the other hand have the tendency to create the best possible product they can master. This often ignores the commercial realities of business and can damage the profitability of the company.
- The information and level of detail needed to perform costing activities is not clearly defined. This is because most organisations have not invested

as heavily in cost estimating as in other areas. This gap between the two groups of cost estimating leads to inconsistencies in costing practices.

- The process of cost estimating is not standardised and is seen as informal. This leads individuals in creating their own process and collecting their own individual data and information. This makes it impossible to produce repeatable results with validated information and it almost makes it unfeasible to reuse an estimate at a later stage of the product lifecycle. Finally the training of other co-workers in the practice of cost estimating is hindered due to the above.

Both, CE-C and CE-E are essential during the conceptual product development stage for design evaluation, and thus optimisation. Although this research recognises that some improvements have taken place with regard to joint working; the two groups are still reasonably isolated from each other.

The researcher believes that the reason behind the above effects observed is the fact that there is not a formal framework in developing cost estimates at the conceptual design stage involving both CE-C and CE-E.

1.2. Research Aim

In view of the above research problem area and context, the main aim of this research is:

Research Aim:
To improve the internal cost estimating practices at the conceptual design stage within the automotive industry environment.

Providing a framework to integrate the two disciplines and a common data infrastructure for cost estimating is the major focus of this research. If the activities are properly aligned, they will provide better quality cost estimates (more objective and less risk) at the very early stages (conceptual design) of product life cycle, and thus help during conceptual design evaluation.

1.3. Scope of the Research

The research concentrates in the automotive industry and in hardware cost estimating. Nonetheless, other industries and sectors are considered to provide a more generic.

The author is concerned with developing a structured and consistent method with which cost estimating experts from commercial and engineering backgrounds can derive their cost estimates based on a common approach.

Both CE-C and CE-E are active throughout a project lifecycle, from the conceptual design stage to the support and disposal of a product. It is usual within the automotive industry that a vehicle is changed within three years in production ("facelift"). The same happens in the aerospace industry where, for example, an air system is upgraded after a period in service. In order to focus the study and achieve the aim set, the author limited the research to the conceptual design stage in the automotive industry. He also interviewed aerospace companies in order to explore the validity of his work with other manufacturing environments. The literature review and the interviews conducted with experts throughout this study have also demonstrated that it is at the conceptual design stage where most confusion and misunderstandings between the CE-C and CE-E occur.

1.4. Research Collaboration

This PhD research is derived from the ICOST project (EPSRC Grant No. GR/N 21321), which addresses two main issues: 1) The data and information requirements for cost estimating and the improvement of the internal practices, and 2) The knowledge and training requirements for cost estimators. This PhD thesis addresses the first part of the research covered in the ICOST project, which is the area of information infrastructure and integration. The ICOST project involves another researcher, Miss Keren Mishra, who was responsible for the other part of the conducted research. Some interviews in this thesis were conducted jointly by both researchers, although the analysis of them was performed separately.

The development of this research began through collaboration with Cranfield University, EPSRC (Engineering and Physical Sciences Research Council), BAE SYSTEMS, Ford Motor Company, XR Associates and Price Systems. In the next sections, a background of CE in the automotive partner of this project is presented.

1.4.1. The Sponsoring Companies – Ford Motor Company

Today, Ford Motor Company is the world's largest producer of trucks and the second-largest producer of cars. The company has operations in more than 30 countries, and employs more than 340,000 men and women at its factories, laboratories and offices around the world. Additionally, about 60,000 companies worldwide supply Ford Motor Company with goods and services. The company's annual sales exceed the gross national products of many industrialized nations. In 1998, Ford Motor Company sold more than 6.8 million vehicles worldwide (Ford, 2001). Ford Motor Company is ranked second on the Fortune 500 list of the largest U.S. industrial corporations, based on sales. In 1998, worldwide sales and revenues totalled $142.6 billion. Net income, excluding one-time items, was $6.5 billion. Although Ford Motor Company is best known as a manufacturer of cars and trucks; it produces other products, including industrial engines, glass, plastics, and a wide range of automotive components. Ford also is established in many other businesses-including financial services, automotive replacement parts, and electronics.

<u>Cost Estimating in Ford Motor Company</u>

Cost estimators are located in different places around the globe. Most cost estimators have an engineering education or background. They have a wide range of expertise in manufacturing processes and tool room capabilities. They are also educated in financial and business skills or are suitably trained to meet the global demands of the business environment in which they operate. They fully understand best industry standards for all manufacturing processes required to manufacture components for the automotive industry. They maintain their competency through continuous technical training, supplier visits, trade shows and ongoing research. The department is divided into several sections which are responsible for individual product programs and matrix managed by the appropriate product financial managers in Product Development. These sections are responsible for all actions which affect commodities on their specific programs, both forward and present model. Two 'core groups' provide support on specific major commodities.

The majority of parts that make a Ford vehicle are actually manufactured by external suppliers. To effectively manage this substantial vehicle cost, cost estimators in North America and Europe define the processes, materials and standard components necessary for the manufacturing of vehicle parts. Cost estimates are used at different stages in the life of a vehicle program. They can be used to support the financially derived affordable cost targets; through the design/development of a vehicle they can help engineers achieve targets; finally they can be used to support purchasing/supplier negotiations. In support of these requirements, estimates include a high level of technical detail. This detail includes physical specifications of the machine used to produce a part, quantity and cost specifications of raw materials, standard part requirements, labour and overhead burdens.

Ford has its own estimating software package called CAPE (Computer Aided Parts Estimating). CAPE is an advanced knowledge based global system designed to evaluate best processes and optimal costs for the manufacture of outside purchased part worldwide.

1.4.2. The Sponsoring Companies – BAE SYSTEMS

BAE SYSTEMS employs over 100,000 staff. They are the result of a merger between the formerly known British Aerospace (BAe) and Marconi Electronic Systems (MES). BAE SYSTEMS is the 2nd largest defence contractor, the joint 3rd largest aerospace and defence company, and the 3rd largest aerospace electronics company in the world (BAE, 2001). They have a simple yet ambitious aim: to be the benchmark aerospace and defence systems company worldwide.

BAE SYSTEMS offer their customers a global capability in land, air, and sea. They design, develop, produce and support armored combat vehicles, major and minor caliber naval guns and missile launchers, canisters, artillery systems and intelligent munitions. In the air, BAE Systems delivers advanced military air capability through major aircraft programmes in the UK, US and to many overseas customers. In the sea, BAE Systems has a breadth of capabilities and is delivering high performance through a range of warships, submarines, auxiliary vessel programmes and naval armaments

Cost Estimating in BAE SYSTEMS

Cost Engineering is a division of the functional groups within the company. The sponsoring group in the company works with costing in the area of aerospace engineering and is responsible for developing costing processes, methods and tools. The cost engineering work enables product optimisation by utilising technical, production and commercial information. Because of their function, important information about cost is brought back to the designer during the early stages of design for better decision making.

1.4.3. The Sponsoring Companies - XR-Associates

XR Associates Limited was founded in 1992, in conjunction with Ford Motor Company to help them achieve their strategic objectives. Today they have a large client portfolio and a diverse range of products and tailored solutions (XR, 2001).

They are an ISO-9002 registered company, and are widely recognised as one of the leading manufacturing consultancy and training providers in the UK and are ranked within the Top 10 in Europe, delivering over 4,500 workshops, training over 18,000 people annually. XR Associates provides training in the area of total cost management.

1.4.4. The Sponsoring Companies - PRICE SYSTEMS

Founded in 1975, PRICE Systems developed the first commercially available parametric estimating models for use in government and industry. Originally developed by RCA for use internally to crosscheck bottom-up project estimates on projects such as the Apollo Program, the PRICE parametric models proved more cost effective, accurate and reliable than other methods (Price Systems, 2002).

PRICE Systems, L.L.C. is a global software licensing and professional services business providing Fortune 1000 companies with enterprise cost management and analysis solutions. PRICE is the market leader offering estimating systems, consulting and training services, and cost research. PRICE solutions enable organizations to automate key business processes that deliver competitive advantages by reducing cost and effort while increasing accuracy. The revolutionary PRICE Systems approach to data mining and modelling brings speed, discipline, learning, repeatability, accuracy, and flexibility to a process that is supported traditionally by ad hoc methods.

PRICE H is one of the most popular products of the company. It is used to estimate costs, resources, and schedules for hardware projects such as electronic, electro-mechanical and structural assemblies. It can be used to estimate hardware projects of any scale, from the smallest individual component to the complex hardware assemblies of a complete aircraft, a ship or a space station. PRICE H can generate remarkably accurate estimates even when using minimal known project data, so that many alternatives can be cost-examined before designs and bills of material are finalized. The application accomplishes this by supplying internally-generated, industry-average values wherever actual data is not yet specified.

PRICE H uses a parametric approach in estimating to simplify input, improve flexibility, and speed computation. This method does not require endless parts lists and labour resource charts for input, as do conventional, bottom-up estimating methods. Instead, PRICE H uses more general attributes to create a representation of the hardware to be estimated. The essence of this parametric approach is to use characteristics that can be easily quantified, such as weight and size, to estimate variables that are more difficult to quantify, such as cost and production schedules. The multitudes of cost relationships among these variables, known as Cost Estimating Relationships (CERs), form the cost engine of the application.

1.5. Thesis Structure

Figure 1-4 illustrates the thesis structure, which outlines the approach taken to satisfy the aim of the thesis.

In Chapter 2, a structured account of related literature is reviewed. The importance of data and information requirements as part of the cost estimating process is investigated. Data and process modelling techniques are reviewed in order to identify the most suitable approach in creating the data infrastructure. Functional decomposition techniques, functional analysis and requirements capture are some of the topics covered where the current theories are analysed and compared. Finally the actual methods of preparing estimates are reviewed and analysed.

In Chapter 3, the reader is introduced to the thesis research methodology and objectives. To fulfil the objectives of the research, the author reviews different research methodologies and presents a critical review of them. This process assists him in designing an appropriate research strategy to satisfy the aim of this thesis.

Chapters 4, 5, 6 and 7 describe the main research contributions and how each of the research objectives is met. Chapter 4 describes the AS IS study. This is the initial data collection performed using semi-structured interviews and a questionnaire. The results confirmed that CE-C and CE-E do not interact well at conceptual design stage and the way design specifications impact on cost is not identified. The lack of a data infrastructure is also observed across organisations.

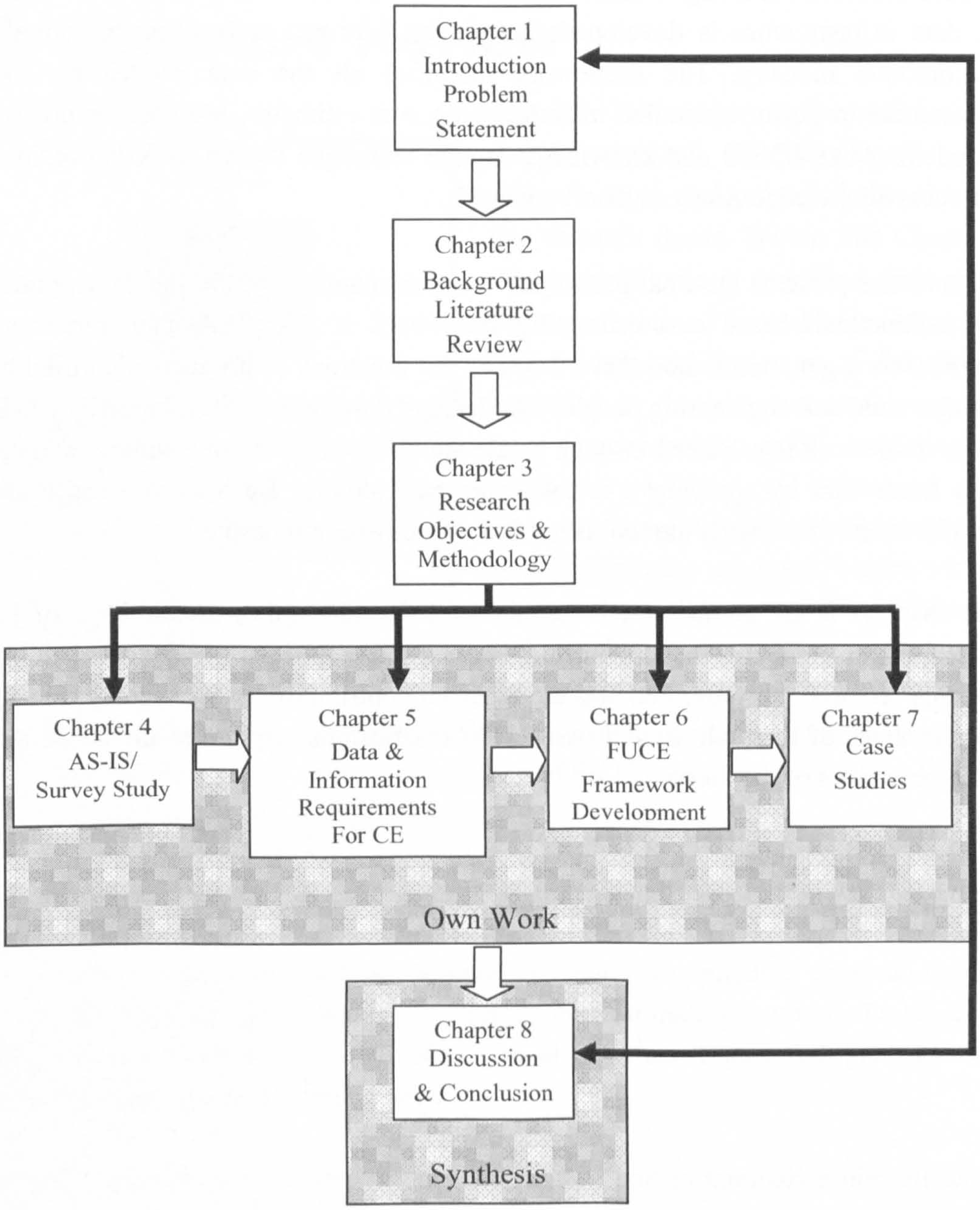


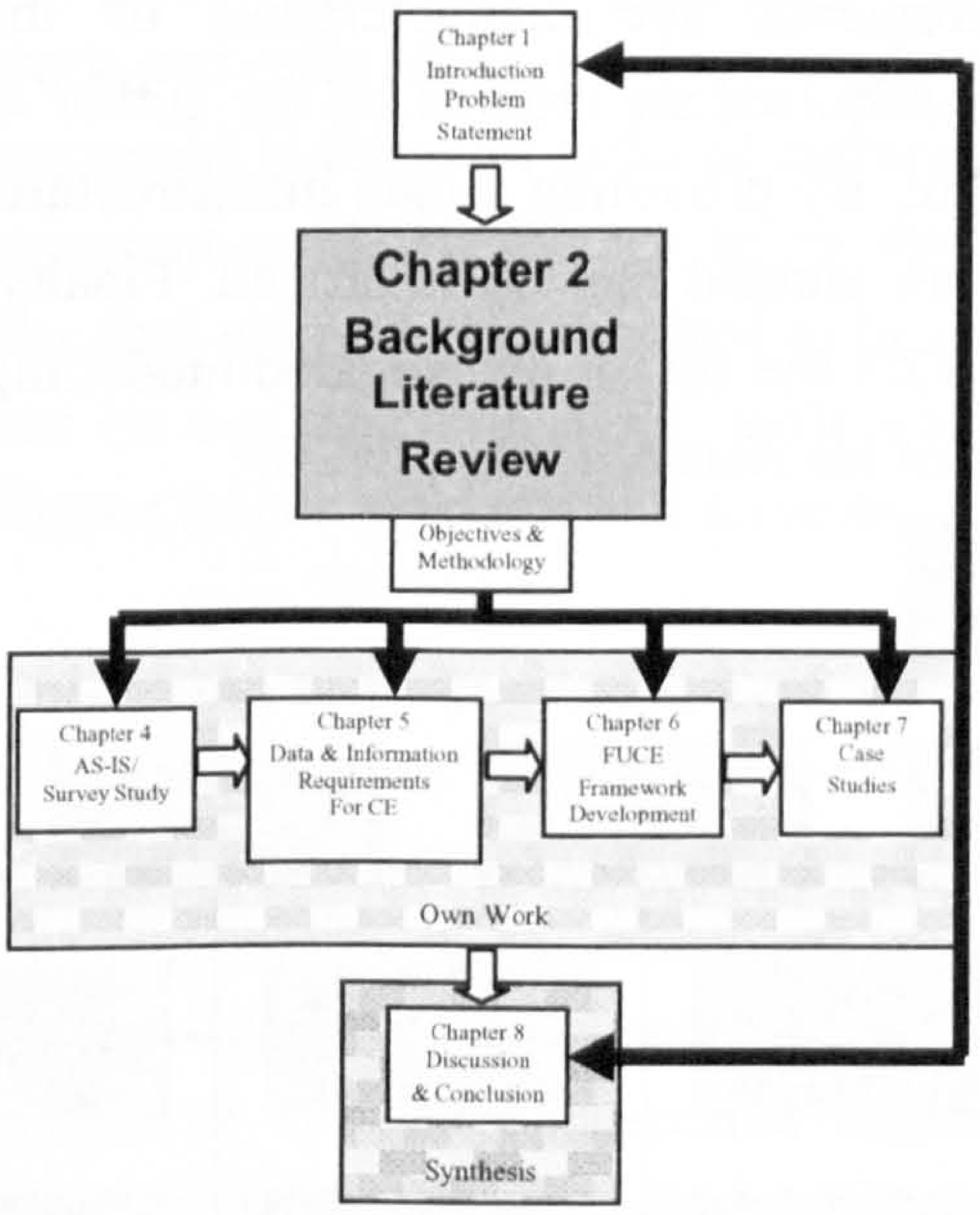
Figure 1-4: Thesis structure

These conclusions, along with the review of the literature lead to Chapter 5, where a data infrastructure is developed for use by hardware cost estimators in the automotive industry. The framework identifies all the data needed by cost estimators to perform detailed manufacturing cost estimates. Methods of process modelling like IDEF3 and knowledge capture technique known as X-Pat (eXpert Process Knowledge Analysis Tool) are used.

The author presents the final part of his work in chapter 6 where the development of a functional-based cost estimating framework is described. The framework represents a generic method that integrates the functions of products identified by commercial and engineering people, to a detailed cost estimate developed by CE-E. The framework is validated through a case study. In Chapter 7 the author validates the framework by applying it to two more case studies. He tries to identify any implications that arise if the tool is used in the aerospace industry.

In chapters 8 the author concludes his work by discussing the findings of his research and compares them to current theories and practices. The key observations of this research are presented and the research contribution is highlighted. Finally future areas of research are discussed. The conclusions respond to the stated aim and objectives of the thesis.

2. Literature Review



The introduction gave a forward for the thesis, provided the context for the research topic and presented the aim of this research thesis. Within this Chapter, the research topic is examined through a structure review of the available literature. The fundamental argument of the thesis presented in the previous section stated that commercial and engineering disciplines within cost estimating can work in a more formalised and integrated manner, within a common framework at the conceptual design stage. The literature review will provide evidence to support this argument. Without this review, it would not be possible to adequately defend the arguments nor the need to carry out the research. With this in mind, the main aim of the Chapter is:

Chapter Aim:
To examine the tools available to Cost Estimators and how to better manage the costing process at the conceptual design stage.

The author reviews through the literature techniques applied in other domains, which he could apply in conjunction with the cost estimating methods. To achieve this aim, the Chapter is divided into several Sections. Figure 2-1 presents the different areas covered by the review.

In order to perform the research in CE the author had to familiarise himself with the terminology and the definitions of cost. Section 2.1 explains the notion of cost and how it is occurred during the product lifecycle. The different types of cost are explained along with definitions of fixed costs, direct and indirect costs, etc.

The main theme of the thesis is the interaction of CE-E and CE-C and the creation of a common framework to integrate their activities at conceptual design stage. For that reason the author investigates and analyses the different techniques used by CE-C and CE-E (Section 2.2). The issues surrounding the conceptual design stage with regards to costing are reviewed and the importance of the design specification is considered by the researcher as an integral part for linking costs and conceptual design stage. For that reason value engineering and functional cost analysis techniques are assessed in Section 2.3. Section 2.4 is devoted to the area of data and information. The information requirements, the characteristics of the information and the sources where it can be acquired are studied by the author in order to assist him with the data infrastructure. By providing a data infrastructure, the consistency in the way cost estimates are created can be improved. Finally, except the cost estimating domain, in Section 2.5 the author investigated modelling techniques that will help him with the design of his research (Chapter 3).

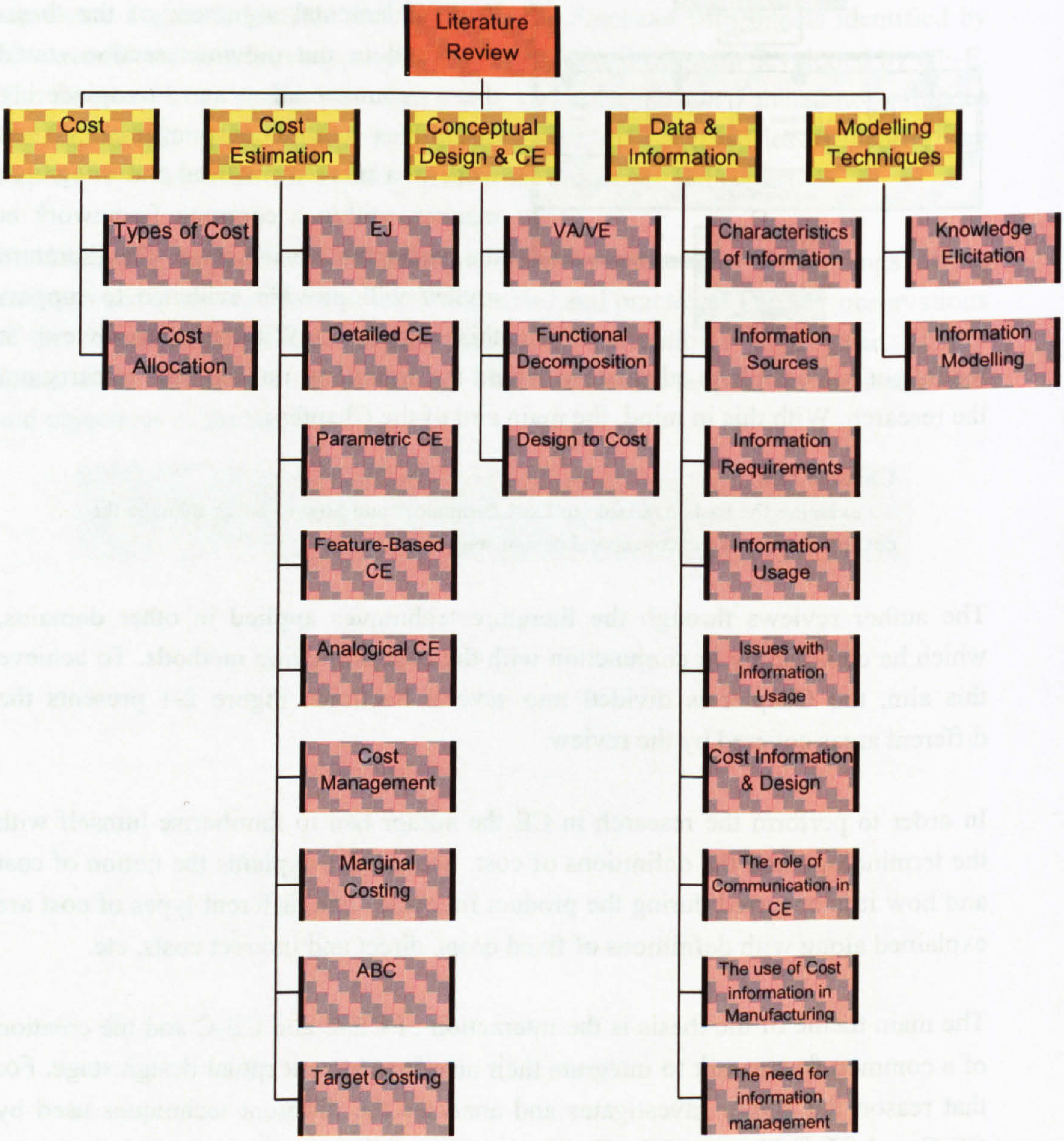


Figure 2-1: Literature review map

2.1. Cost

The broad definition of costs is related to the economic resources (manpower, equipment, real facilities, supplies and all other resources) necessary to accomplish work activities or to produce work outputs (Stewart, 1995a). Usually, costs are expressed in terms of units of currency. Therefore, costs are the amount of money representing the resources spent for the production of output. A resource is a physical entity that is required to be able to execute a certain operation. Resources can be e.g. machine tools, tools and fixtures, but also operators and materials. Output can be products and services.

During the product development cycle, engineering tasks also cause fixed costs. Figure 2-2 shows the influence of several company departments on the product costs as taken from a German research project in machine design (Wierda, 1990). The engineering tasks cause costs because of their contribution to the development of a product. At the start of the product development cycle, no costs are fixed yet (Figure 2-3). The consecutive engineering tasks fix the costs because of the decisions taken. The decisions taken during an engineering task at the beginning of the product development cycle can significantly influence the costs caused by engineering tasks later in the engineering cycle because the solution space for the engineering tasks is reduced by it. Figure 2-2 shows that design itself takes only about 10% of the product costs, whereas it fixes about 70% of the product costs. It has been argued that the latter percentage is misleading because the product specifications already imply some minimal costs. According to Ehrlenspiel, design is responsible for 20 to 30% of the total product costs (Wierda, 1990).

The way in which engineering tasks contribute to the product costs depends on the production environment. Figure 2-4 shows a comparison between high-tech production and classic mass production (Thompson, 1998). The figure shows that for high-tech production the costs caused before production are about 5 times higher than for mass production, while the costs of production are about one fifth. For mass production, it is required to be able to estimate the costs of production more accurately than the costs of design and engineering. For high-tech production, the opposite applies.

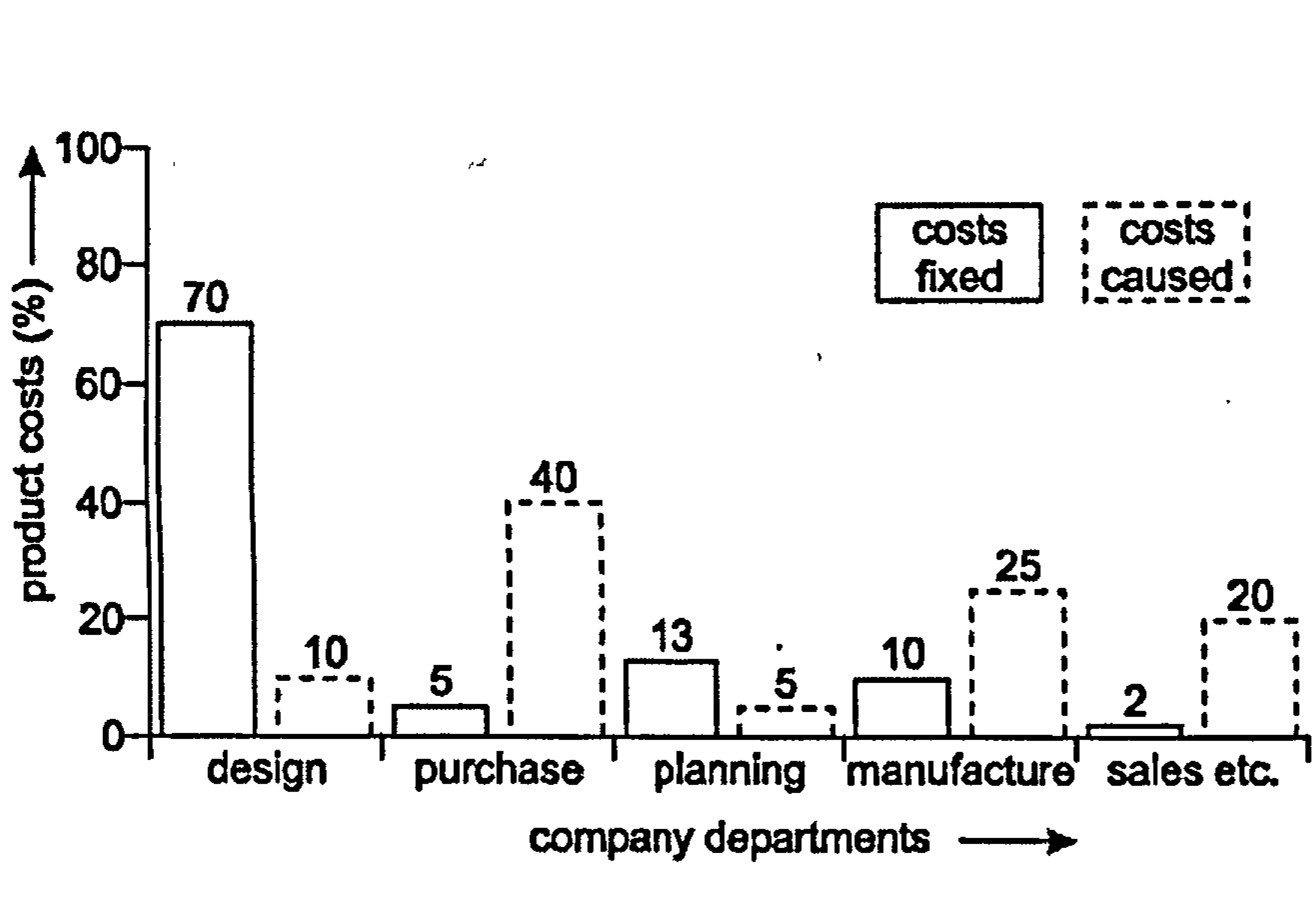


Figure 2-2: Experimentally determined influence of the main departments of a company on the product costs (Wierda, 1990).

It is easier to estimate costs accurately when more detailed information is available. Since design fixes about 70% of the product costs, it is required to make accurate cost estimates during design. However, during the design process the product information is not yet available in full detail, so it is difficult to make accurate estimates. This phenomenon is known as the cost estimation paradox, see Figure 2-5.

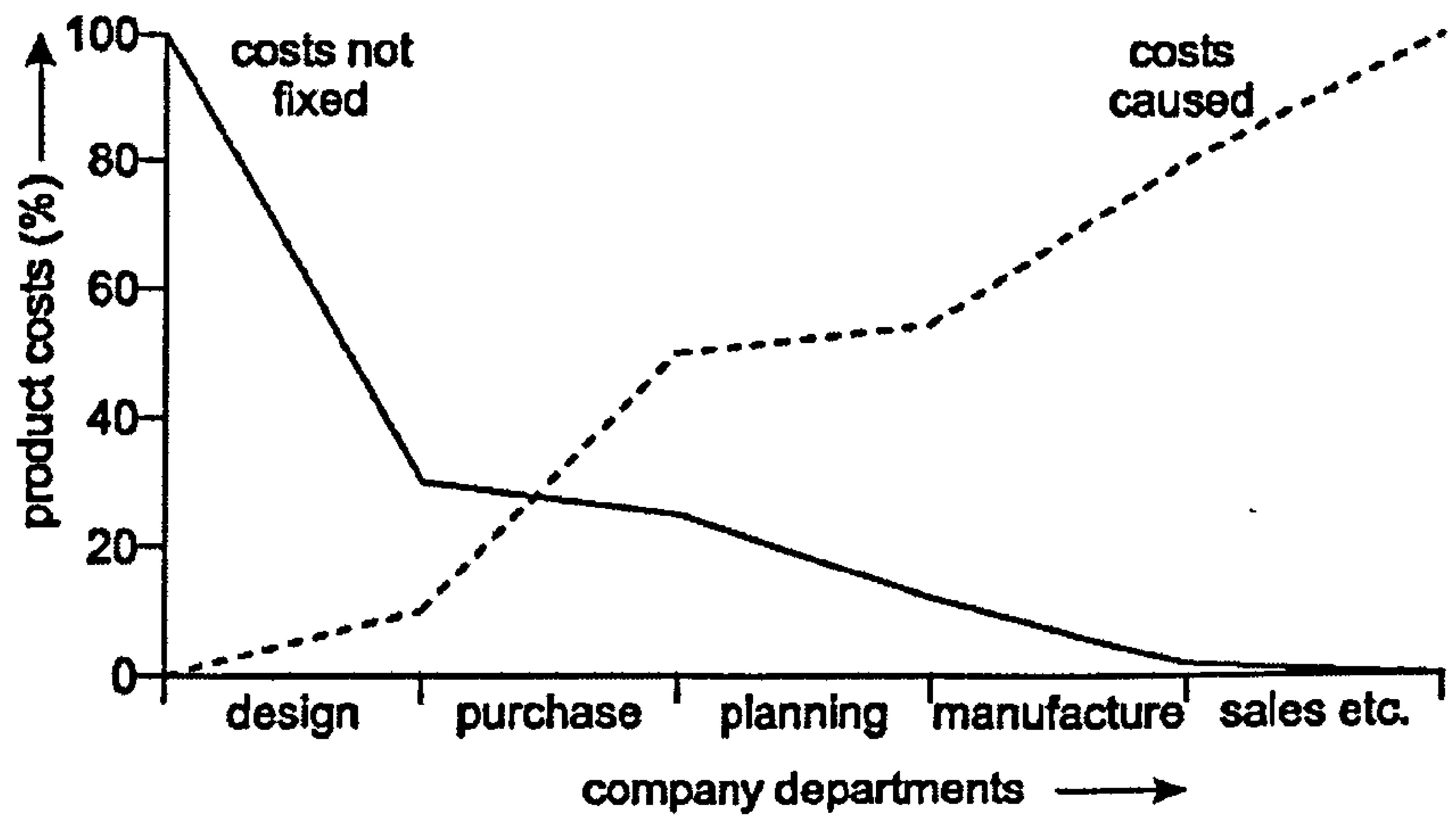


Figure 2-3: Decreasing costs not fixed and increasing costs caused during the product development cycle (Wierda, 1990).

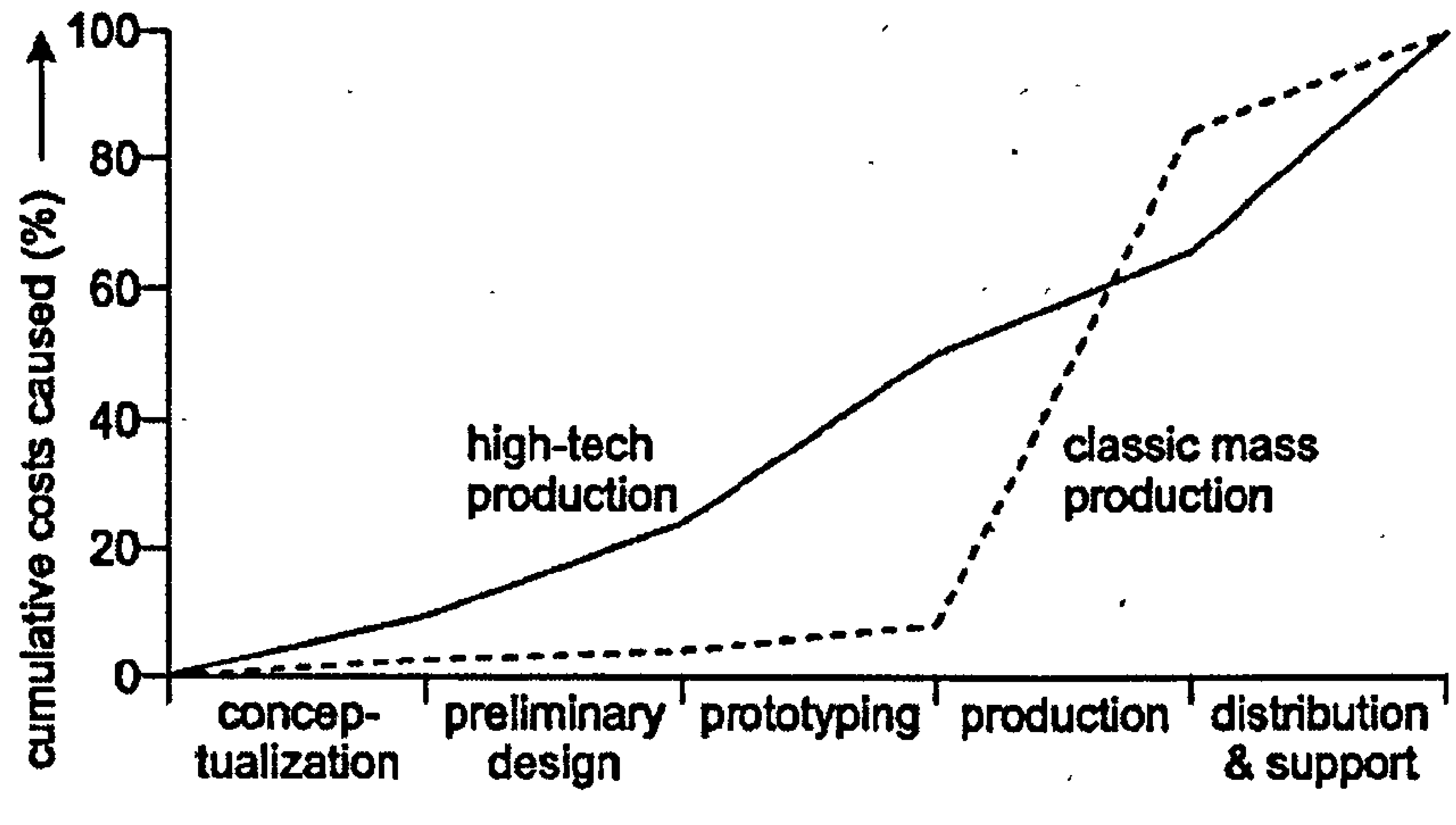


Figure 2-4: Product life-cycle costs (Thompson, 1998)

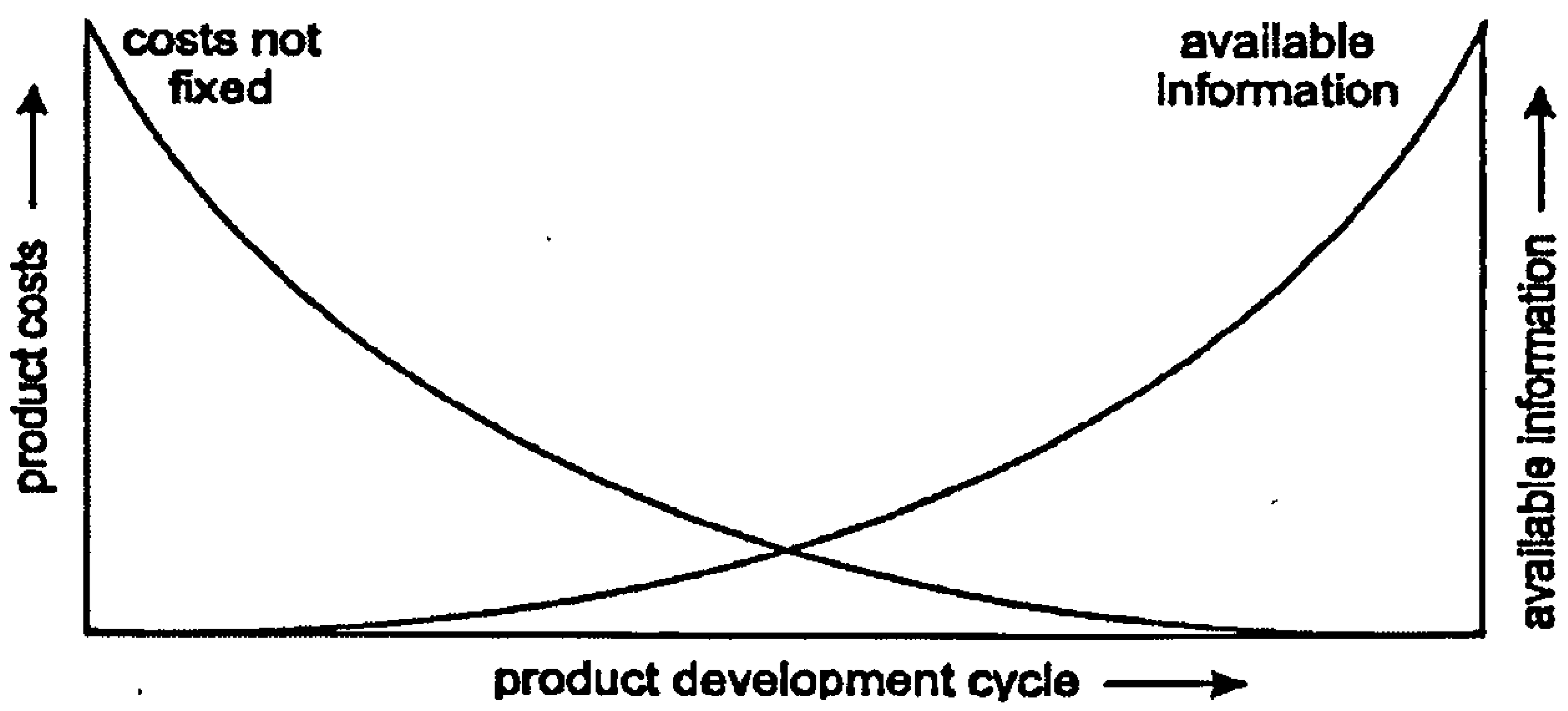


Figure 2-5: The cost estimation paradox (Bode, 1998a)

2.1.1. Types of Cost

Total product costs are composed of several different cost items. Possible breakdowns of the product costs are the cost breakdown structures of Fabrycky & Blanchard (Asiedu, 1998) and Liebers (1998) (Table 2-1 and Table 2-2). These two examples show that multiple breakdown structures are possible. A general cost breakdown structure seems hardly possible. Two important criteria for a good cost breakdown are: all costs must be covered and no costs must be counted twice.

Table 2-1: The cost breakdown structure of Fabrycky & Blanchard (Asiedu, 1998).

Total product cost			
Research and development cost	Production and construction cost	Operations and maintenance cost	Retirement and Disposal cost
- Product management - Product planning - Product research - Design documentation - Product software - Product test and Evaluation	- Manufacturing/ construction management - Industrial engineering and operations analysis - Manufacturing - Construction - Quality control - Initial logistic support	- Operations/ maintenance management - Product operation - Product distribution - Product maintenance - Inventory - Operator and maintenance training - Technical data - Product modification	- Disposal of non-repairable - Product retirement - Documentation

The costs from a cost breakdown structure are caused by different resources and the way these costs are related to those resources can be different. In order to get a better perception of costs, costs are classified in different types according to their cause and the relation to their cause. Therefore, it is advantageous to know the costs per cost type.

Two general cost classifications are on the one hand *direct* versus *indirect* costs and on the other hand *variable* versus *fixed* costs. Direct costs are costs that can be identified specifically and consistently with an end objective (such as a product, service, software, function, or project), while indirect costs cannot be identified specifically and consistently with an end objective (Shuford, 1995). This means that direct costs can be allocated directly, i.e. the allocation base is known, whereas for the allocation of indirect costs an allocation base has to be defined (Cooper, 1991).

Variable costs are costs that change with the rate of production or the performance of services (Stewart, 1995a). Fixed costs are costs that do not vary with the volume of business (Stewart, 1995a). Furthermore, semi variable costs and step-fixed costs can be distinguished. Semi variable costs are costs that vary somewhat in relation to volume, but their percentage of change is not the same as the percentage of change in volume (Shuford, 1995). Step-fixed costs are fixed costs that alter their behaviour as the activity level moves from one relevant range to another (Shuford, 1995).

Table 2-2: The cost breakdown structure of Liebers (Liebers, 1998).

Product cost			
	Costs of executing a production plan		
Costs of generating a production plan - Marketing and promotion - Company management, including control - Sales and order intake - Resource, process and product design - Process planning - Production planning	Costs of successfully executing a production plan - Having production resources - Using production resources - Materials included in the products - Waste	Costs of re-planning - Repair, rework and scrap - Resource repair, including down time - Late delivery	Externally imposed burdens - Contingency allowances - Cost increasing taxes (as opposed to profit reducing taxes)

The distinction between *recurring & non-recurring* and *relevant & irrelevant* costs is also often used. Recurring costs are repetitive costs that vary with the quantity being produced (Stewart, 1995b). Non-recurring costs are elements of development and investment costs that generally occur only once in the life cycle of a work activity or work output (Stewart, 1995b). Relevant costs are costs that are present in one of several alternatives but are absent, either in whole or in part, in other alternatives (also called differential costs) (Shuford, 1995). These costs play a role in specific decision-making processes, whereas all other costs are irrelevant costs (Liebers, 1998).

Other cost types that are frequently distinguished are listed here to illustrate the diversity of cost types:

Acquisition costs:	Total expenditures estimated or incurred for the development, manufacture, construction and installation of an item of physical or intangible property, or the total acquisition costs of a group of such items (Stewart, 1995a).
Conversion costs:	A grouping of direct labour and manufacturing overhead into a single summary cost element (Shuford, 1995).
Development costs:	Costs of a system up to the point where decision is made to procure an initial increment of the production units or the operational system (Stewart, 1995a).
Disposal costs	The costs of disposing of a facility, property item, equipment item, scrap, by-products or excess material

	(Stewart, 1995a).
Life-cycle costs	All costs incurred during the projected life of the system, subsystem or component (research, development, test, evaluation, production, maintenance and disposal) (Stewart, 1995a).
Opportunity costs:	Loss of income due to not selecting the optimum alternative from a financial point of view (Liebers, 1998)(Blommaert, 1998).
Prime costs:	Costs of direct material and direct labour (Shuford, 1995).
Removal costs:	The costs of dismantling a unit of property owing to retirement from service (Stewart, 1995a).
Sunk costs:	The total of all past expenditures or irrevocably committed funds related to a program/project (Shuford, 1995).

2.1.2. Cost allocation

The allocation of cost is important for a correct interpretation of costs. Cost allocation is a method or combination of methods that results in a reasonable distribution of costs (Stewart, 1995a). For direct costs, this allocation is straightforward. The costs can be calculated from:

$$C = P \times Q \tag{2.1}$$

with: C: the costs

P: the price variable

Q: the allocation base

In the case of direct labour costs, C is the direct labour costs; P is the hourly rate and Q the number of hours. In the case of indirect costs, the allocation base has to be defined. After this, the price variable can be calculated from:

$$P = C_i / Q \tag{2.2}$$

with: P: the price variable, usually called rate

C_i: the indirect quantity

Q: the allocation base

The values of the indirect quantity and the allocation base can be obtained from historic information or from prognoses or a combination of both.

If, for example, the total direct costs are chosen as the allocation base for the total indirect costs, P is the direct cost burden rate, C the total indirect costs and Q the total direct costs. When the rate is known, the costs can be calculated with equation

2.1. This example illustrates the way in which indirect costs are calculated with the *traditional costing* method. With this method, the overhead is allocated to products using volume based allocation bases e.g. labour hours, machine hours. When the allocation base is chosen incorrectly, incorrect conclusions can be drawn from the indirect costs. When the indirect costs are calculated with the direct cost burden rate, it would mean that every product with high direct costs also has high indirect costs, which is not the case. Therefore, this can lead to wrong conclusions about the cause of costs.

The ratio between direct costs and indirect costs has changed drastically over the past decades because of increasing automation, in both machinery and computers, as illustrated by Figure 2-6 (Thompson, 1998). In the 1950's, the indirect costs were only a small part of the total product costs while direct labour constituted the biggest part of the total product costs. Therefore, it was not necessary to estimate the indirect costs in a very detailed and accurate manner and traditional costing was an adequate way to calculate the overhead.

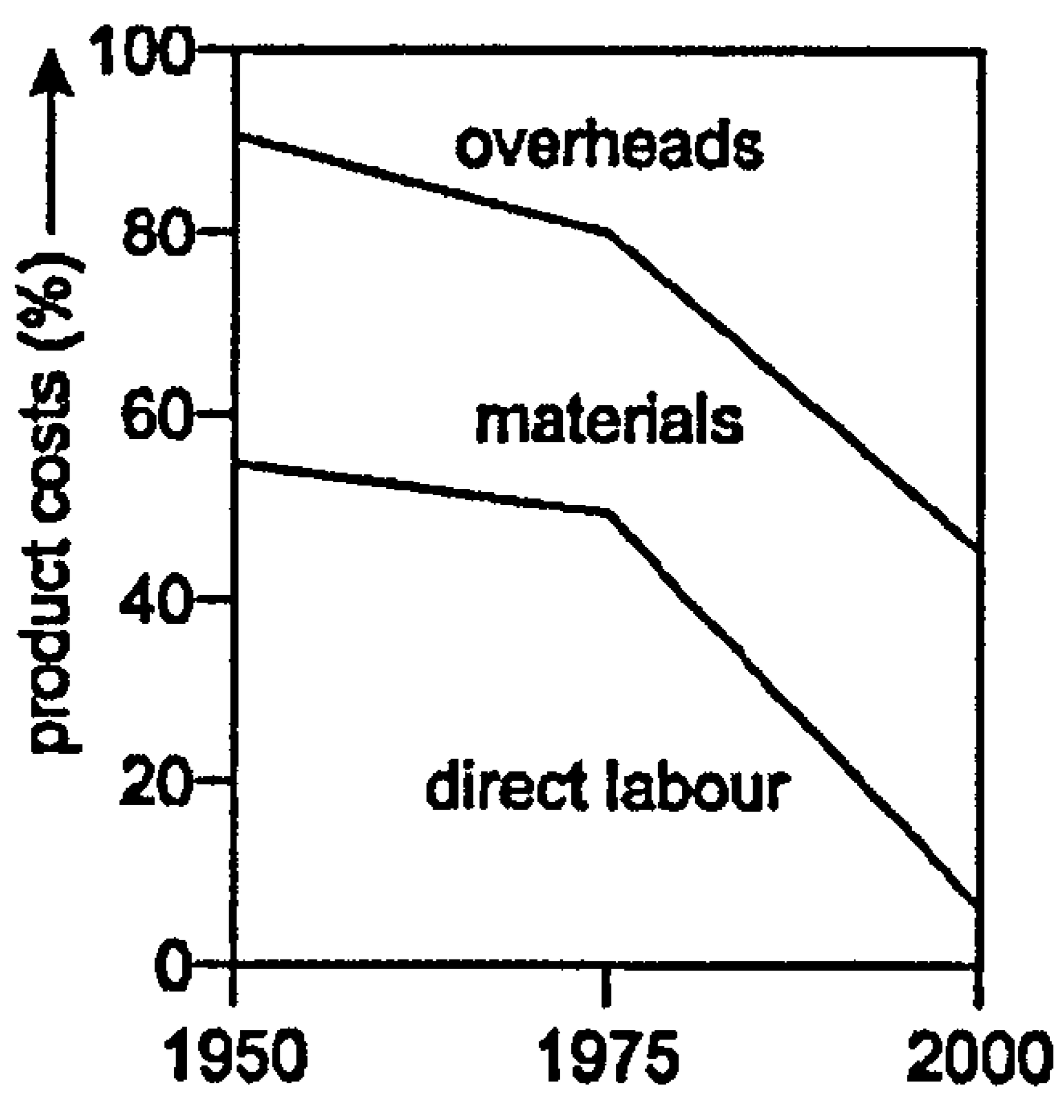


Figure 2-6: The components of product costs in the United States (Thompson, 1998)

Nowadays, the opposite situation is true. Overhead constitutes the biggest part of the total product costs while the direct labour costs are only a small part. The part of the material costs in the total costs has hardly changed. Because of this change, it has become necessary to calculate the overhead more accurately and more detailed. The allocation of the overhead requires the use of other allocation bases that allocate the overhead in a more realistic way. Other methods for the allocation of overhead costs will be discussed in section 2.2.8.

Analysis:

- Previous researchers so far have established that design fixes around 70% of the product cost. As the author investigates the interaction between CE-E and CE-C, it is important to analyse the type of activities they perform at this stage. Section 2.2 will look at the techniques and activities performed by Cost Estimators. In section 2.3 an analysis of the conceptual design stage and CE will be performed.
- According to Thompson (1998) the manufacturing costs are the most important to organisations involved in mass production like the automotive industry. Nonetheless the cost breakdown structures that have been proposed by Fabrycky *et al.* and Liebers do not address specifically that fact. They relate more to overhead product costs. The author believes that a breakdown structure provided for specific industries will be more valuable to Cost Estimators in order to establish manufacturing costs. This structure should relate more to the type of techniques used by Cost Estimators within that industry. This will part will be addressed further at Chapter 5 where the author researches a data infrastructure for the automotive industry.
- According to Stewart (1995a), traditional cost can attribute wrongly the overhead cost allocated to products. The author will investigate literature in the area of Activity Based Costing (ABC) in Section 2.2. It is also noted by the author that a data infrastructure should take into account the ABC principles into consideration.

2.2. Cost Estimation

To understand better the issues between CE-C and CE-E we need to look into more detail the use of CE and how it is defined. Furthermore the author investigates the different techniques and processes utilised by both groups. By reviewing the techniques the author obtained an understanding that will be useful in the next stages of his research where a large amount of interaction with CE experts will occur to complete his studies. Furthermore a review of the costing methods will allow the author to make a better judgement about which technique will be more useful to achieve his aim.

CE can be defined as "the prediction of the cost of a product before its actual manufacture" (Aderoba, 1997). Cost estimation predicts costs related to a set of activities before they have actually been executed (Shehab, 2001). It works closely with cost management. Cost estimation feeds information to cost management. In today's manufacturing environment these two are not anymore inseparable from each other, they are interlinked. The definition for cost estimation is not fixed. A related term commonly used for it is cost engineering. Humphreys (1996) defines cost engineering as "the application of scientific and engineering principles and techniques to problems of cost estimation, cost control, business planning, and management science".

Cost estimation and cost management are used together to predict future performance and to control and manage resources of the company (Stewart, 1995). They help companies to succeed in their objectives. Cost estimation produces estimates which are used along with cost accounting information by cost management. Cost management uses this information to manage and control the corporation. Cost estimation is needed for getting better cost information as early as possible that would not be otherwise available.
Cost estimation differs from cost accounting because cost accounting is based on the actual usage of resources (Hyder, 1999). Cost estimation needs plenty of information; some of it might come from cost accounting but majority of the information is collected from the various sources using various different methods.

Analysis:

- Shehab describes in his work that cost estimating works closely with cost management. His definitions could relate to this research between those of CE-E and CE-C (Section 1.2). CE-E produce the estimates, CE-C manage them. This point is also put forward by Stewart (1995). This establishes the importance of the two groups and how vital it is that they work together.
- Stewart argues the importance of producing cost estimates as early as possible during the product development. What his study does not investigate is the use of the design domain in order to assist in this task. He instead concentrates on different cost estimating techniques, which are analysed in the next sub-sections. The author believes that is important to look at how the product specifications and product functions that are established at the conceptual design stage can be used to help CE.
- Hyder (1999) explains that CE-E need plenty of information in order to prepare those estimates and explains that this information can be acquired from various sources. His research does not progress to explain those sources, how they can be identified or how this information should be grouped. The author investigates further the issue of information and data in Section 2.4

In the next sections the major cost estimation methods are evaluated. These techniques have been developed and have evolved over time in response to the changes in manufacturing. This is the case especially in cost estimating at an earlier stage in product development life cycle. However it should be noted that no method is usable during the whole life cycle, some are better than others depending on the context (Farineau, 2001). During conceptual design, parametric and analogical methods are most important as products are not completely defined, although it is rare that using these two methods are sufficient (Duverlie, 1999).

2.2.1. Expert Judgement

Expert judgement can be called the first "original cost estimation method". These estimates are based on the past experience of the estimator. This experience is based on similar problems or products encountered by the estimator previously. Therefore these estimates are based on the familiarity of experts into the problem domain, e.g. their knowledge of manufacturing processes and materials.

Expert judgement is not based on empirical data or methodology therefore it is a subjective method. When cost estimating new products cost estimators have to make numerous assumptions and judgements. Hughes (1996) mentions that there is not much research on how cost estimators actually use expert judgement to make cost estimates. Some research has been done which has found that this method is subjective and uses plenty of intuition (Rush, 2001). This uncertainty in how expert judgement is used when creating estimates is partly related to the fact that the reasoning of the argumentation is unstructured. Hughes (1996) also points out that the accuracy of expert judgement cost estimates depends on both sound data and availability of this information.

Expert judgement, according to Sheppard (Sheppard, 1997) is one of the most widely used cost estimation methods. This is partly because expert judgement is widely used during the creation of detailed and activity-based cost estimates. These more elaborate methods are also bounded by the limitations of subjective expert judgement. Often a portion of them are intuitively constructed. That is because cost estimates quite often require extensive use of judgement in order to produce a meaningful result.

Analysis:

- It can be concluded that if the reasoning behind the cost estimate is unclear then it is not easily possible to verify how accurate or valid the estimate is. Non experts (and in this case CE-C) cannot always accurately analyse or question the rationale behind the estimate, therefore making their job more difficult when it comes to negotiations or other activities performed by them. This use of expert understanding can speed up the cost estimation process but it decreases the transparency of cost estimates. The author believes a process where the assumptions regarding a specific product are captured assists the interaction of the two groups.
- The importance of accurate and consistent data is raised again as an issue as in the previous section. Nonetheless there is no proposition or reference to other research performed to standardise it and presented.

2.2.2. Detailed Cost Estimation

The detailed cost estimating process consists of a number sequential steps that "flow together and interact to culminate in a completed estimate" (Stewart, 1995). Figure 2-7 shows the anatomy of a detailed estimate. This figure illustrates graphically how the various cost estimate elements are synthesised from the basic man-hour estimates and material quantity estimates. Man-hour estimates of each basic skill required to accomplish the job are combined with the labour rates for these basic skills to derive labour-pounds estimates. In the meantime, material quantities are estimated in terms of the units by which they are measured or purchased, and these material quantities are combined with their costs per unit to develop detailed direct material pound estimates. Labour overhead or burden is applied to direct material costs. Then general and administrative expenses and fee or profit are added to derive the "price" of the final estimate.

The labour rates applied to the basic man-hour estimates are usually an average of the rates within a given skill category. For example, the engineering skill may include draftsman, designers, engineering assistants, junior engineers, engineers and senior engineers. The number and titles of engineering skills vary widely from company to company, but the use of a group of composite labour rates for the engineering skill category is common practice. The composite labour rate is derived by multiplying the labour rate for each skill by the percentage of man-hours of that skill required to do a given task and adding the results.

Cost estimators who make detailed cost estimates have to have a good understanding of the product being estimated, and the materials and manufacturing processes used to make the product. The mere understanding of the individual elements is not sufficient but the cost estimator also needs to know relationships between these different components to create cost estimates (Farineau, 2001). For this reason the expert judgement relied on as the analysis of cost impacts of each choice is complex.

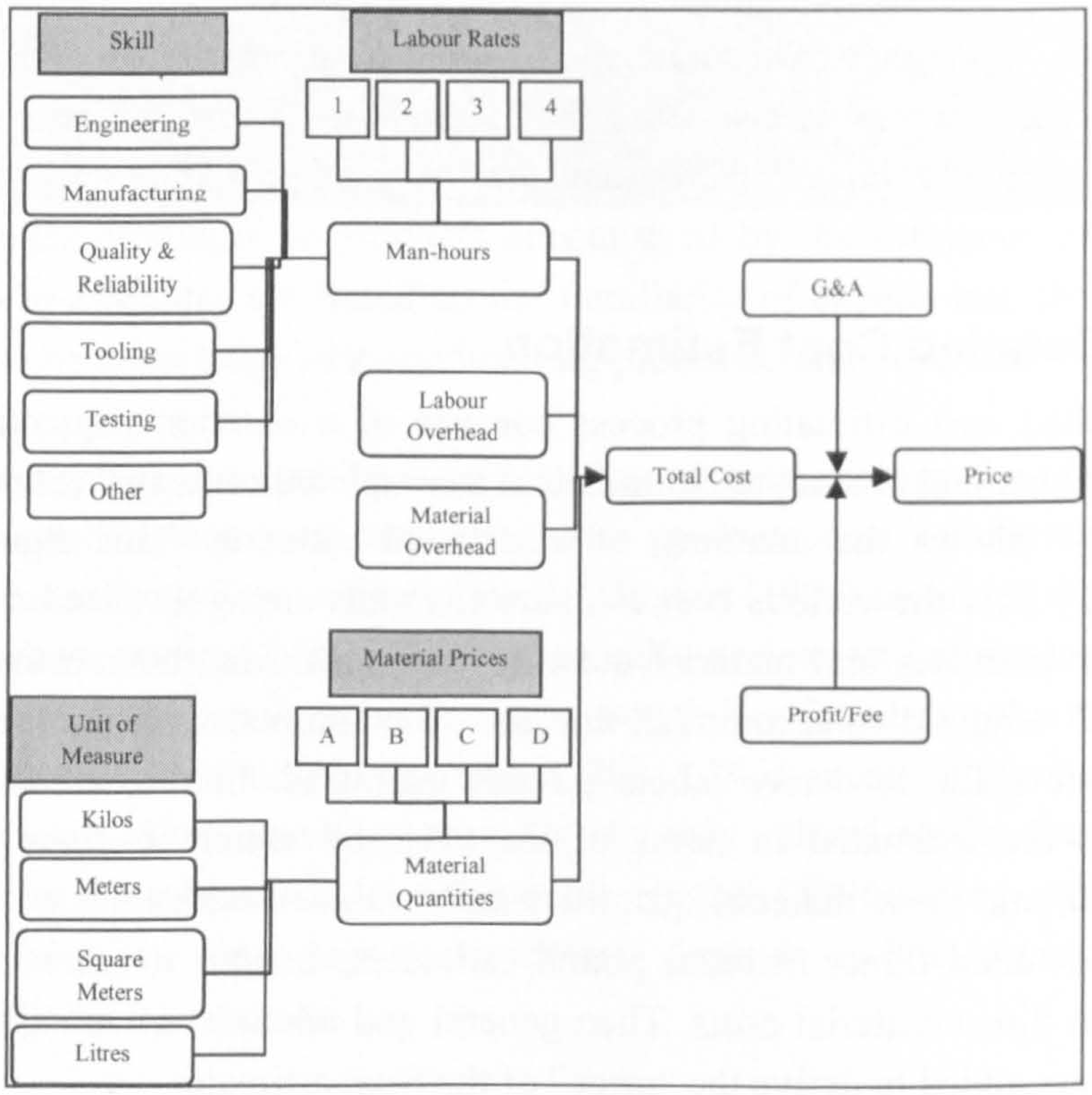


Figure 2-7: Anatomy of detailed estimate (Stewart, 1995)

Like activity-based costing (ABC), detailed estimation is used after conceptual design in the product life cycle, especially during production. The method gives precise results but it requires detailed product and manufacturing process information but this information is rarely known and accessible during the design phase. This is a major disadvantage of this method as it requires knowledge of engineering intent and material specifications to produce a truly accurate estimates. Also it relies on continuity and judgement of the cost estimator to be able to repeat similar cost estimates in exactly the same way. The accuracy of this method depends on how well the cost elements of a detailed cost estimate are known and how well their costs have been estimated (Zhang, 1996b).

Detailed cost estimation is very dependent on correct information but when a product is well defined and understood it is a common cost estimation method to use (Farineau, 2001).

Analysis:

- Stewart explains that the detailed (or bottom-up) approach requires the expert to understand the manufacturing process very well in order to model it. The author found from his research (Section 4) that indeed CE-E possess that manufacturing knowledge and he believes a model could be constructed to take advantage of the detailed cost estimating approach at the conceptual design stage. He tries to demonstrate that in Chapter 6.
- Although Farinau has found that EJ is widely used again for the creation of bottom-up estimates, it is quite clear from his work that this structured approach provides a standardisation of a sort for developing a cost estimate. The author believes that this standardisation can be taken an extra step further into developing cost estimating templates for specific commodities based on past products. This is investigated further in Section 6.
- Farinau observes that the detailed method is used after the conceptual design stage, where a design and material specifications are available to the CE-E. The author although accepting the above comment, believes that if assumptions are presented in a consistent way and relationships are created that capture the different requirements possible, a reusable framework can be established that can be used for the commodity's costing.
- Both Zhang and Farinau raise the issue of how important it is to have accurate and dependable information available to create the estimates. Again there is no work on the information itself needed in order to develop the estimates. The researcher has already established a trend in the need for a data infrastructure. The literature verifies that point so far and highlights that one of the objectives of the research (developing a data infrastructure) is valid.

2.2.3. Parametric Cost Estimation

Parametric estimation uses mathematical relationships to estimate costs. It uses assumptions or historical data from previously completed projects for generating these estimates (Bashir, 2001). The method depends on good data supplied by a database. Parametric estimation can be used before having described the product completely and that is one of the reasons for its popularity. There are at least three types of parametric methods (Farineau, 2001): (1) scaling the most significant technical parameters of the product (e.g. mass, material) to defined ratios. Using these linear relationships it is possible to quantify the cost of the product; (2) universal models which are a set of statistical relationships which are supposed to be universal. Various software packages use universal models such as MAP-H, PRICE H or SEER-H; and (3) cost estimation relationships (CER) which are mathematical relationships relating the cost of a product to identified cost drivers. CERs are normally custom made for a specific purpose using statistical analysis.

Parametric estimation has certain advantages as for example CERs are easy and fast to use. For example designers can use CERs to optimise their work thus reducing costs (Duverlie, 1999). But parametric methods have also serious disadvantages. As having incomplete information happens quite often cost estimators have to guess missing parameters. Because of the usage of these assumptions the method works like a "black box". It is difficult to understand important elements of the manufacture and to be able to justify results (Duverlie, 1999). The traceability of costs is not the best characteristic of parametric methods. They cannot solve particular cases. They are based on statistics so they can only show general trends.

Analysis:

- According to the authors, parametric estimating owes its popularity to the fact that it can be used before the product description is complete and that there are universal models that can be applied. The fact though still remains that engineers are asked in many cases to second guess parameters that they do not know.
- Estimators end up arguing the costs based on the parameters they chose of these commercial factors instead of the actual product. For example, these commercial packages have a "complexity factor". Complexity factors are provided based on examples. Two estimators could argue on different values (1.5 or 1.3) therefore ignoring the product itself and the manufacturing challenges it might present and concentrating on those figures.
- Parametric models do not provide sufficient explanation with regards to certain selection like materials and manufacturing process decisions, thus

making it very difficult to understand and explain the estimate e.g. in a negotiation with a customer or a supplier.

- The author believes that the use of CERs could possibly be combined with the detailed bottom-up method, thus allowing the benefits of both techniques at the conceptual design stage.

2.2.4. Feature Based Costing

Feature based costing (FBC) is another form of parametric estimating. The growth of CADCAM technology and that of 3D modelling tools have largely influenced the development of FBC. Several researchers are investigating the integration of design, process planning and manufacturing for cost engineering purposes using a feature based modelling approach (Wierda, 1991).

FBC has not yet been fully established or developed with respect to cost estimating. Although feature based costing is gaining popularity, there are limitations for using features for the costing process. There is no widely accepted consensus on what a feature is across the disciplines of an organisation. This problem is magnified when viewed across companies and industries. For example, there are several levels of features definitions. A feature of an aircraft could be a wing, yet this wing contains many parts, each of which consists of many lower level features. Therefore companies are also left to decide how to cope with the changing product definition and applying an appropriate feature based CER (Rush, 2000). Thus, the feature based costing approach is not yet fully established and the implications are not yet completely understood. Nonetheless, companies find the concept 'appealing'.

The issue of standardisation does not only exist for FBC but indeed for all the methods and disciplines in cost estimating. Groups like ISWG (International Standards Working Group) of the ICEC (International Cost Engineering Council) have been formed to try to tackle the problem (ICEC, 2002). The researcher also hopes to contribute to this area with the outcomes of his research.

2.2.5. Analogical Cost Estimation

Analogical methods evaluate the cost of products by comparing them with the cost of already existing products. These methods try to find functionally similar products as possible to create an estimate. The implicit assumption is that similar products have similar costs. By comparing products and adjusting for differences it is possible to achieve a valid and useable estimate. Analogical estimating relies on components having been estimated before and the cost estimator will use this historical data as a guide to create a new estimate for the new component. The case-based reasoning (CBR) is one of the most popular of analogical methods and it uses information systems to aid to produce cost estimates (Duverlie, 1999; Whitaker, 1989). Like other analogical methods CBR also uses past solutions for solving problems.

CBR relies on a feature description base and thus it requires a number of past cases in order to be effective. CBR works by first recognising the problem, comparing it with older design solutions, and choosing the best fit, i.e. the most similar solution for the problem (Tessem, 1997). The following step, adaptation, is the most important step; here the new estimate is created by modifying the older one based on the previous cases. It is possible to use estimator's experience but it is also possible to use parametric estimation techniques or other mathematical models to choose a case (Duverlie, 1999). Case-based method chooses right type and parametric methods handle fine-tuning. The final step is the evaluation of the new estimate and recording learned lessons to a database. This recording is an important feature of CBR as enables the ability to learn from past cases.

Advantages of CBR are better transparency than using parametric methods. Estimators can see information sources thus making corrections. Past cases can also be like a collective memory of the enterprise (Farineau, 2001). Like parametric methods it is also fast and low cost to use but unlike parametric it can be used for particular cases (if a similar case exists in the database). This example also illustrates disadvantages of CBR. It relies heavily on similar past cases. The quality of the linkage between two cases used for comparison is important. Finally implementation of CBR requires plenty of time, information and effort (Duverlie, 1999). These might be the most likely reasons why there are so few examples of CBR for cost estimation (Perera, 1998).

2.2.6. Cost Management

Cost management is the main role performed by CE-C. Sections 2.2.6 to 2.2.10 are dealing with the activities and tasks performed by CE-C. Cost estimation is one of the starting points for cost management. It provides services (or information and knowledge) for several cost management activities, such as for target costing and value engineering (Cooper, 1997). Therefore, quality of cost estimates have direct influence how decisions are made during cost management activities (e.g. influences on the go, no go decision concerning a new development). This means that a too low cost estimate leads to less profitable products and a too high estimates loss of business opportunities.

Strategic cost management is managing costs for both financial and competitive advantage, and cost accounting and management are tools for implementing its objectives (Grundy, 1996). Activity based management which uses the information developed under activity based costing (ABC) have plenty of similarity with strategic cost management. Both concentrate on the management of the business to improve the value received by the customer and the profit achieved by providing this value. When going into a more pragmatic level, management accounting contains plenty of functionality of both cost accounting and management. It provides information for example for product valuation, pricing, policy formulation; planning, decision making, variance analysis and cost control (Williamson, 1996).

There are several techniques that are used by cost management and CE-C. Cost control is an important activity in an automotive company. It is used at various levels of management within an organization to ensure that the costs incurred fall within acceptable levels. The most common financial accounting techniques for doing cost control are budgetary control and standard costing, which highlight and analyse any variances (Williamson, 1996). A standard cost is a performance target and actual performance is measured against this standard. Standard costing is the analysis between standard and actual costs therefore enabling to find out reason for the differences. For example, a variance may occur when suppliers increase prices of a component. Using variance analysis it is possible to evaluate different options for how do deal with the issue.

Besides financial accounting methods there are several other relevant cost management methods used in the manufacturing industry. These methods are marginal costing, activity-based costing, target costing, value engineering, design-to-cost and benchmarking (Chen, 1997; Kulmala, 2002; Williamson, 1996).

2.2.7. Marginal Costing

Another basic cost management tool is marginal costing (Kloock, 1997). Some authors use the term variable costing for marginal costing. It is a costing and decision-making method that splits up the cost into a variable and a fixed component. The method charges only the marginal costs to the cost units and treats the fixed costs as a lump sum. These fixed costs are written-off in full against the aggregate contribution. The cost information used during the marginal costing can be based on cost estimates although quite often the information is based on historical information.

The usefulness of marginal costing comes from the fact that the separation of fixed and variable costs help with the understanding for making managerial decisions. It can provide information e.g. for cost-volume profit analysis in which cost estimators can assess the point at volume needed at which neither profit nor a loss is made.

2.2.8. Activity-Based Costing

Activity-based costing creates cost estimates by summing up product costs. The difference between detailed cost estimation and ABC is that ABC uses more elaborate techniques to handle the allocation of non direct costs, i.e. costs not directly attributable to a particular item.

ABC relies on the ability to be able to identify the activities that create the product (Innes, 1994). When creating an ABC estimate, first activities within an organisation are identified and costs associated for each of these activities are identified. This means that those costs which do not fall into the direct cost categories are attributed to these supportive activities. After this costs of each activity are attached to products in proportion to how products are using activities. The cost of the activity for a product is the cost of one activity times the number of times the activity is required to produce the product (Zhang, 1996b). Summing up all these costs with direct costs provides the cost estimate.

ABC provides a more accurate cost estimate than a detailed estimate because ABC enables the distribution of the overhead cost more accurately to products which consume resources (Innes, 1994), for example ABC does not take a blanket cost rate for production overheads. What makes ABC popular is that often companies (when still using older systems) find that did not fully understand the true cost of their products and therefore made some poor business decisions. ABC assigns indirect cost more accurately and gives greater visibility to manufacturing activities, such as planning and control. ABC is ideal for optimising production and identifying high costs of manufacturing processes. It more realistically allocates costs into small batches. Most of the companies which have implemented ABC have succeeded (to various degrees) in more accurate product costing, better cost management, better cost control, better allocation of overheads, and more accurate cost information (Innes, 1994). The organisations adopted ABC because it provides critical decision information, such as product pricing, investment on product engineering and most optimum product mix. ABC ensures that a fair share of overheads is paid.

There are numerous articles and case studies outlining the benefits of implementing ABC in manufacturing and service operations. Maisel and Morrissey (1993) summarize some key expectations from implementing an ABC system. Brimson (1991) lists ways that activity accounting can be used to help a company. The following list is compiled from these sources as the key areas for improvement to be gained from ABC techniques, and where the information is most frequently used by companies:

- To identify which products make the most profit or loss.
- To identify which activities can be performed more economically or restructured to create greater value for the customer.
- To identify performance measures to achieve manufacturing excellence, which can be used to spur the continuous improvement of business processes.
- To provide feedback on the effects of actions that are implemented, that is, "Were the anticipated results obtained?"
- To identify the costs of quality (including costs for prevention, inspection, and costs of product failures).
- To identify costs of support operations included in the cost of getting the product to the customer (material handling, maintenance, marketing, and engineering)
- Use information to improve "make/buy" decisions, and more accurate assessment of product life cycle costs.
- Use information for strategic product decisions, and link these to the analysis of operational activities.

Of course the principle of ABC is good but there are limitations in it too (Zhang, 1996b). The allocation is based on historical or estimated data. Cost estimation cannot truly provide such accurate information so that allocation of information can be used as described in the ABC research. In practise the method has its limitations, as does detailed cost estimation.

Consultants have had mixed success in implementing ABC projects. There are many accounts of successful implementations, but relatively few on the failures. Some of the problems arising from ABC are:

- Too much detail: work on how much detail is necessary, rather than on how much can be obtained. The more detail included, the greater the cost to implement and maintain the system.
- Too little detail: company changes from old cost system to a multiple pool, multiple driver cost system which is much better than the old system, but still does not provide enough information to manage activities in the company.
- Problems collecting data: activity definitions not well defined, data reliability in question, expensive and time consuming methods of data collection (e.g. surveys).
- Inaccurate assignment of costs of activities to products: costs are allocated to cost objects using drivers which do not seem rational to users.
- Unavailability of detailed data: task level data is not maintained, and summary detail does not allow item-by-item cost tracing.
- Costs assigned to the wrong year: need to use life cycle product costing, which conflicts with financial accounting treatment (recognizes costs in the period incurred).
- Software problems: difficulties integrating ABC software with other systems.
- System is too costly to maintain: ABC systems are expensive to maintain, requiring revisions to reflect continual changes to the organization. Compared to traditional standard costing procedures, these systems have a high overhead cost, and require considerable more data inputs.

The author believes that ABC has been developed on sound principles and should be utilised in organising a database for costing purposes. The author will try and apply the principles dictated by ABC in the data infrastructure that he proposes in chapter 5.

2.2.9. Target Costing

Target costing is as much a technique for profit management as it is for cost management. It puts cost management issues into the central place from the early phases of product development. It can be used throughout all phases of a product life cycle (Cooper, 1997). Target costing intends to reduce product costs while ensuring quality and reliability. This cost reduction is done by "examining all ideas for cost reduction at the product planning, research and development process" (Kato, 1993). The heart of target costing lies a simple equation; Target cost = Target selling price – Target profit margin.

The main idea of target costing is straightforward. In competitive markets, the prices are decided by the market. A number of competitors can offer similar products at keen prices and consumers will expect ever greater value for their money. A car manufacturer has to sell products at a price that the market expects and is prepared to pay. Also the company needs to make a financial return on the products sold. Therefore only the product cost can be changed.

Although target costing can be used to manage the life cycle cost, it is mostly used during the design and development where most cost impacts are made. The author believes that any suggested model he proposes has to take into consideration the importance of target costing.

2.3. Conceptual Design and CE

The author concentrates his efforts on the conceptual design stage. It is therefore important to investigate the relationship between the conceptual design stage and CE.

It is well known that the traditional approach to product development leads to long product development cycles and difficult cost control. The desired approach to product development is a concurrent one with an emphasis on cost control. Studies have shown that the greatest potential for cost reduction is at the early design phase, where as much as 70% of the cost of a product is decided (Dewhurst *et al.*, 1988). As the design phase itself accounts for a relatively small percentage of the total development cost, devoting a greater effort to design to cost is a reasonable and necessary step towards optimising product costs. An effective means of encouraging the designer to design to cost is to provide cost estimates at the design synthesis phase of the design process, where design alternatives are considered. An additional benefit of this approach is that the management and CE-C are provided with an early indication of the scale of the product cost. This enables the management to make more informed bid estimates at the conceptual design phase.

Rehman et al. (1998) suggest a methodology for modelling manufacturing costs at the conceptual design stage based on both case-based and rule-based reasoning. The method is aimed at innovative design and allows the evaluation of such designs through a function. Although the author appreciates the reasoning and the potential of using product functions to model costs, Rehman's approach could not be applied to sub-assemblies or complex products. Furthermore he does not provide a detailed description of his methodology or a case study of any sort.

Ou-Yang concentrates (Ou Yang *et al.*, 1997) on determining cost by shape complexity, product precision and the tooling process. He has integrated his approach with commercial CAD and database packages to provide a demonstration case. Although his approach could be used for specific parts, there is a limitation to the applicability of the model as indeed has been highlighted by Ou-Yang. The major drivers for calculating the cost with his model are based on the machining process and product precision. These are not sufficient as a large manufacturing organisations with mass production products like automobiles have established processes and quality standards. A good example of a cost driver that has not being considered is materials which in manufacturing are likely to be an important cost driver.

Mileham et al., (1993) proposed a parametric approach to cost estimating at the conceptual design stage. With his approach he is able to estimate the cost of a product with minimal component information. The tool was developed to support designers and not the other groups involved in costing. One of the main drawbacks of this approach is the use of parametric estimating. As mentioned in Section 2.2.3 the major drawback of parametric models is that they do not provide sufficient explanation with regards to certain selection like materials and manufacturing process decisions, thus making it very difficult to understand and explain the estimate e.g. in a negotiation with a customer or a supplier.

Weustink et al., (2000) introduce a generic framework for manufacturing cost control, that it is based on design process planning and production aspects. He suggests that the model can help create generic templates where alternative designs could be compared. The author believes that there is not sufficient analysis of the type of data that should be included in the cost estimates, nor are the costing techniques appropriate to be used with his framework.

Pugh (1992) analyses the "top-down" approach for cost estimating before the actual product development begins. His analysis is summarised in the four stages:

1. The collection for completed projects of data concerning their costs and technical characteristics together with the industrial facilities employed by them and the economic conditions under which they were undertaken.
2. Analysis of related data to form cost estimating relationships and apportionment rules. These may be simple or complex and may be derived via statistical analysis or from observations of proportionalities between cost and a measure of size.
3. Compilation of costing assumptions giving the best description of the new project under consideration.
4. Application of the cost estimating relationships (and apportionment rules) to the costing assumptions so as to yield estimated costs for the new project.

The author believes that Pugh's approach, although explained for developing "top-down" estimates, can be used for almost all the other costing techniques. The author believes that the philosophy presented by Pugh and summarised by the four points should be followed as closely as possible by the model created by the author to address his research. They could be used as general guides in the development of this model.

Analysis:

- The author is surprised that although literature does exist in the area of functional analysis and CE, a lot of it is based on designers. It is evident from the methodologies followed by the authors reviewed that very few of them have actually captured and analysed data from cost estimators themselves.
- There is a distinct lack of literature between the interaction of CE-C and CE-E and how these techniques will improve it.
- Milenham's and Pugh's approach, although based solely on parametric approaches, provided an insight into the direction of the framework development the author is considering.
- All the authors state the fact that at conceptual design stage the inputs available to estimators and designers are the requirements and the functions the product needs to fulfil. This provides the author with further directions

for his research analysis. It is the author's belief that if a framework can be constructed that links product functions and cost estimates, a better understanding of cost estimates will be achieved at conceptual design stage.

2.3.1. Value Engineering / Value Analysis

To achieve satisfactory long term profits, resources must also be used effectively. Efficiency implies either minimising the use of inputs for a given level of output, or maximising the level of output for a given level of input. Value engineering according to Cooper (1997) is "a systematic interdisciplinary examination of factors affecting the cost of a product with the aim of devising a means to achieve its specified purpose at the required standards". These standards can be e.g. quality, reliability, or *cost*.

Value engineering activity analyses the design of products to find effective ways to achieve all necessary functions and essential characteristics (Elias, 1998). These necessary functions will define what the product must be able to do or what functions are beneficial to the customer. An important point is that value engineering is often used in conjunction with target costing. Therefore the aim of value engineering is not to minimise cost but achieve specified target costs. Like target costing, value engineering needs cost estimates to make economic evaluations between proposed solutions.

Value analysis originated as an engineering design method to evaluate the functionality of products with respect to the cost of making them. It considers functions defined from the customer/ user perspective, as opposed to the designers' perspective (Dieter, 1983). The fundamental questions asked during value analysis could be rephrased for manufacturing organizations:

-How can a given requirement of the customer be satisfied at the minimum cost?
-What is the value of each process or activity of the organization to satisfying the customer's requirements?
Further analysis of processes could then be achieved by further questions:

-Can one do without this process/activity?
-Does the process do more than is required?
-Does the process cost more than it is worth to the customer?
-Is there some other way to do the job better?

-Is there a less costly way to satisfy the customer?
-Can one outsource the process or function to the benefit of the customer, as well as the organization?
-Is this process one which this company should be doing, or can someone else do it better?

Quality Function Deployment (QFD) is a recent implementation of the value analysis principles. QFD maps the customer requirements to design attributes, and attempts to quantify how much the customer requirement is satisfied by each design requirement. Analysis of the costs of satisfying each design requirement should also be linked to the customer requirements, and whether the customer perceives value in that process step. This is the key to determining if a process is value-adding or non-value-adding. The question that should be asked is; *If the customer doesn't need it, and it adds to expenses, then why do it?* Answering this question, and executing the value analysis outlined above, requires a decision support system that is capable of providing the cost of each process, and some measure of the value added for the customer. Johnson and Sapp (1992) write of "process-based information" as a means for management to maintain competitive advantage. They identify this tie-in of activity costing and process-based information with value analysis and QFD:
"For each product sold, identify the processes that must be performed to satisfy the customer. Be sure to perform those processes. This is the key concept in QFD.
In all processes, identify all sources of delay, excess, and variation that cause waste and impede continuous flow.

Embark on programs to cut lead time and improve flow of information.
Examples include:
Track indicators of time and waste to confirm the success of these programs and to motivate people to do more, such as 'Chart on the wall'/ visual display of performance indicators.

Calculate product costs by adding up the costs of activities it takes to design, engineer, make, distribute, sell and service each product. To do this, use the full arsenal of techniques associated with the concept of activity-based costing."

Analysis:

- As pointed out earlier, the author believes that in order to improve the cost estimating process at the conceptual stage a link needs to be created between functions and product. The author believes that the principles of QFD could be used to create that link.

- Although value engineering has been used to analyse products and reduce their costs, not a lot of research has been done in using functional decompositions to estimate a new product at the conceptual design stage. This research is analysed in the next section.

2.3.2. Functional decomposition

Functional decomposition originated with Value Engineering (VE) in the 1960s in the USA. Among its first users were Univac-Sperry Rand, Ford, General Electric and Chrysler (Creasy et al., 1973, Yoshikawa et al., 1994). There are numerous functional modelling methodologies, all of which follow a similar approach. They begin with an overall product function and then break that function into sub-functions. Pahl and Beitz have developed probably the most well known technique (Pahl et al., 1988). They define function as the "general input/output relationship of a system whose purpose is to perform a task". The overall function is the requirement the design needs to fulfil. Then the function is broken down into sub-functions until the flow of energy, material and signals through the design is clear. Although their approach was important for engineering design, their methodology did not provide an all-encompassing list of sub-functions to describe all possible engineering systems or produce repeatable function structures. Since then many researchers have tried to expand on the principles of Pahl and Beitz (Lai et al., 1989, Iwasaki et al., 1995, Kirschman et al., 1998).

Sturges et al. (1993) described how a support function is the goal of the decomposition, and that such a function is a generic model for "well-known" processes and sub-functions. The authors state that that their technique reduces the compatibility problems inherent in part selection by choosing matching allocation slots.

Collins et al. (1976) developed a list of elemental mechanical functions in the analysis of a helicopter part failure. The author described each failed part in terms of function. In this way he produced a classification consisting of 46 key words and 40 preceding adjectives, which were used to form 105 elemental functions. The result of this research is a list of common functions that have to be considered during the mechanical design of a helicopter. This list of functions, although broad, did not create taxonomy. Kirschman et al. used the research to go a step further by developing a function-based taxonomy of elemental mechanical functions. Through his combination of "basic function groups" and "directions", he developed about 150 combinations of elemental mechanical functions. The authors claim that the taxonomy can be used as a pedagogical tool or as a basis for the derivation of complete taxonomy.

Suh (1990) talks about function in his work on axiomatic design. Here function is defined as the desired output, and the design is decomposed into a hierarchy of functional requirements (FRs) which map directly to design parameters (DPs). Suh uses function at all levels, decomposing the design from the top down, choosing functions and the matching physical forms. He states that although FRs and DPs can be composed into hierarchies, the FRs for a lower level cannot be determined without first determining the DPs at the level above.

Mukherjee and Liu (1997) present an abstraction for conceptual design by using function-form relation matrices. The relation matrices provide a link between purely functional and purely geometric representations, and a means to carry out domain-dependent manufacturability evaluations. Theodoracatos and Ahmed (1994) describe an expert system for conceptual design that interprets functional structures, searches engineering solutions, and evaluates concepts. Tomiyama et al. (1993) proposed a methodology - Function-Behaviour-State (FBS) to model functions and introduce a computerised tool to support functional design based on the FBS modelling. Kimura and Suzuki (1995) attempt to capture and to represent product background information, which includes requirements, specifications, assumptions, constraints, decision history, trial-and-error processes, and other rationale rules.

Kirschman et al. (1996) present a classification system in order provide a standardised approach to analysis, therefore providing a common language. He calls his approach a function-based taxonomy and he identifies four main groups of functions:

1. Motion
2. Control
3. Power/Matter
4. Enclose

From these four basic types of functions, a taxonomy is proposed (table 2-3). Most parts of a mechanical design can be classified into these four categories. These seem to describe the basic functions of a mechanical subsystem. Furthermore

Kirschman goes on in proposing a functional hierarchy for mechanical design (figure 2-8).

Table 2-3: Basic function groups (Kirschman 1996)

Motion	-Rotary, Linear, Oscillatory, other -Create, Convert, Modify, Dissipate, Transmit -Flexible, Rigid
Control	Power, Motion, Information -Continuous, Discreet -Modification, Indication -User's supplied, Internal Feedback
Power/Matter	-Store, Intake, Expel, Modify, Transmit, Dissipate -Electrical, Mechanical, other
Enclose	-Cover, View, Protect -Remove, Permanent -Support, Attach, Connect, Guide, Limit

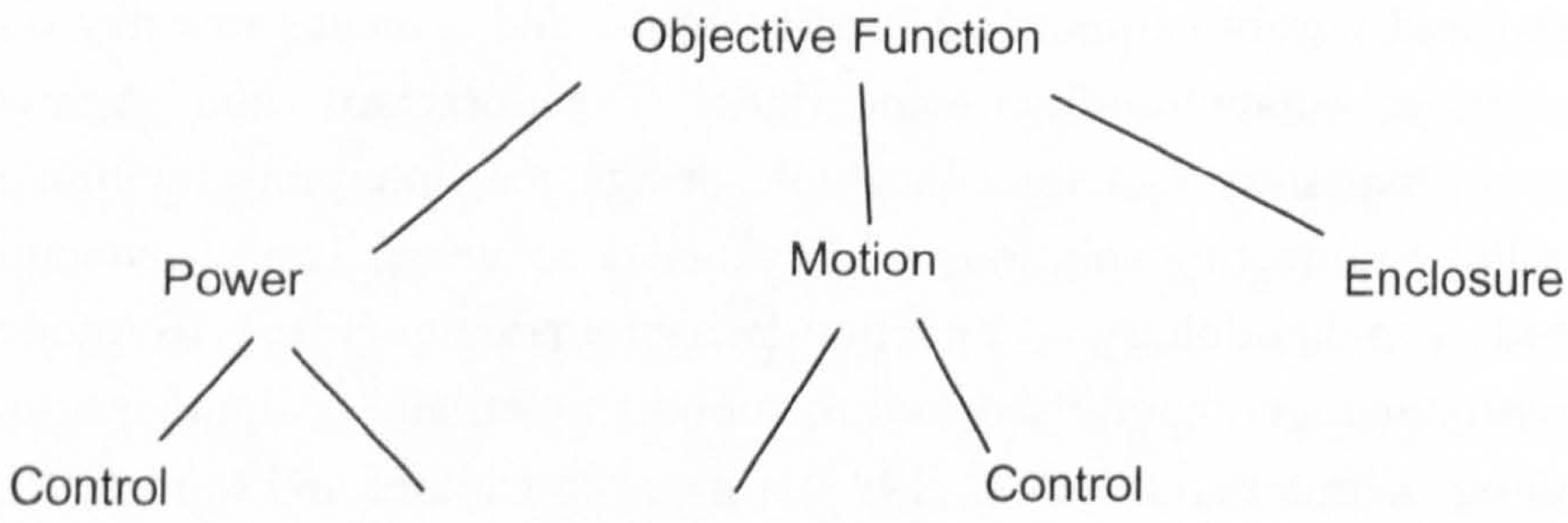


Figure 2-8: Functional Hierarchy for Mechanical Design

He uses as an example the design of a cordless electric drill to test the taxonomy. Drills of this sort are a common consumer good, and are complex enough to show the design process. So the main objective is to "Drill Hole". This is inserted at the top of the functional hierarchy as shown in figure 2-9.

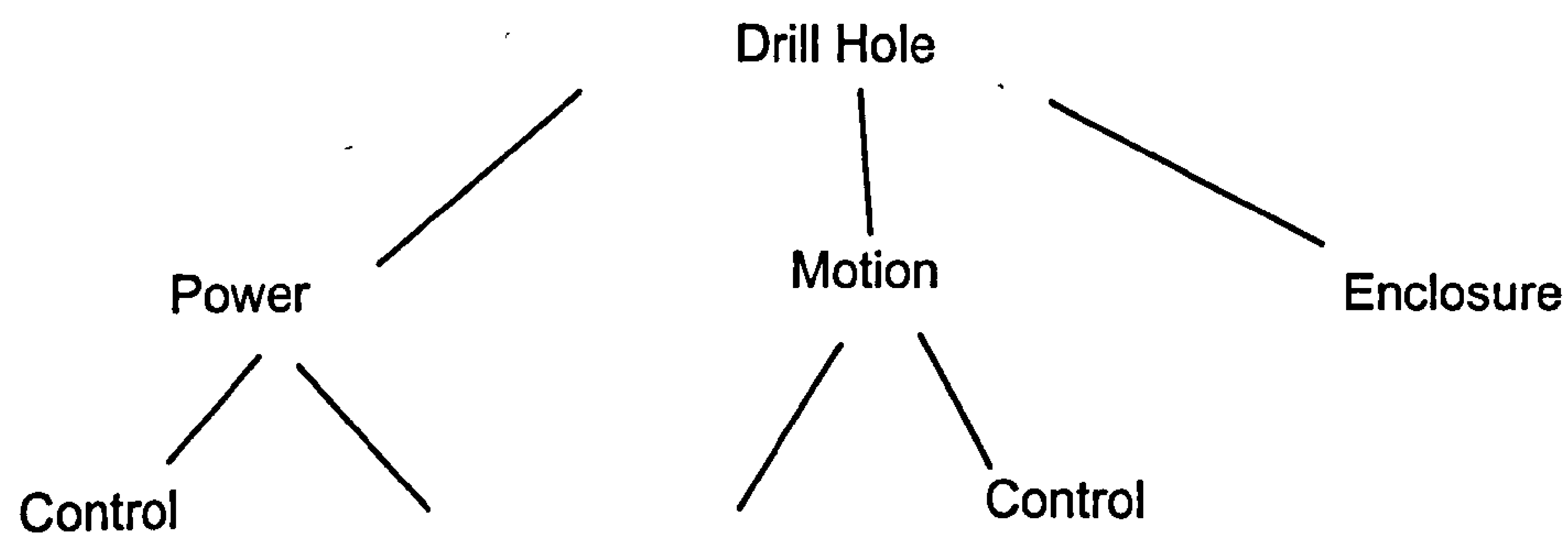


Figure 2-9: Functional hierarchy with specified objective

Next, the designer generates the four top level functions, and selects several components to complete the first level of the hierarchy, Power/Matter, Motion and Enclosure. Possibilities for Power include electric, mechanical, fluid and chemical. In this case the only way to effectively use chemical is in the form of a disposable battery that converts chemical power to electrical power. Fluid power can be pneumatic, since a gas is sufficiently compressible to store power. Mechanical power can come from a flywheel or spring as an energy storage device. Electric power is realised in the form of a rechargeable battery. Since only one type of power is needed for this device, a selection is made from these options.

Kirschman takes on a similar approach to specify the power motion control and enclosure of his model until he arrives at a complete form tree (figure 2-10)

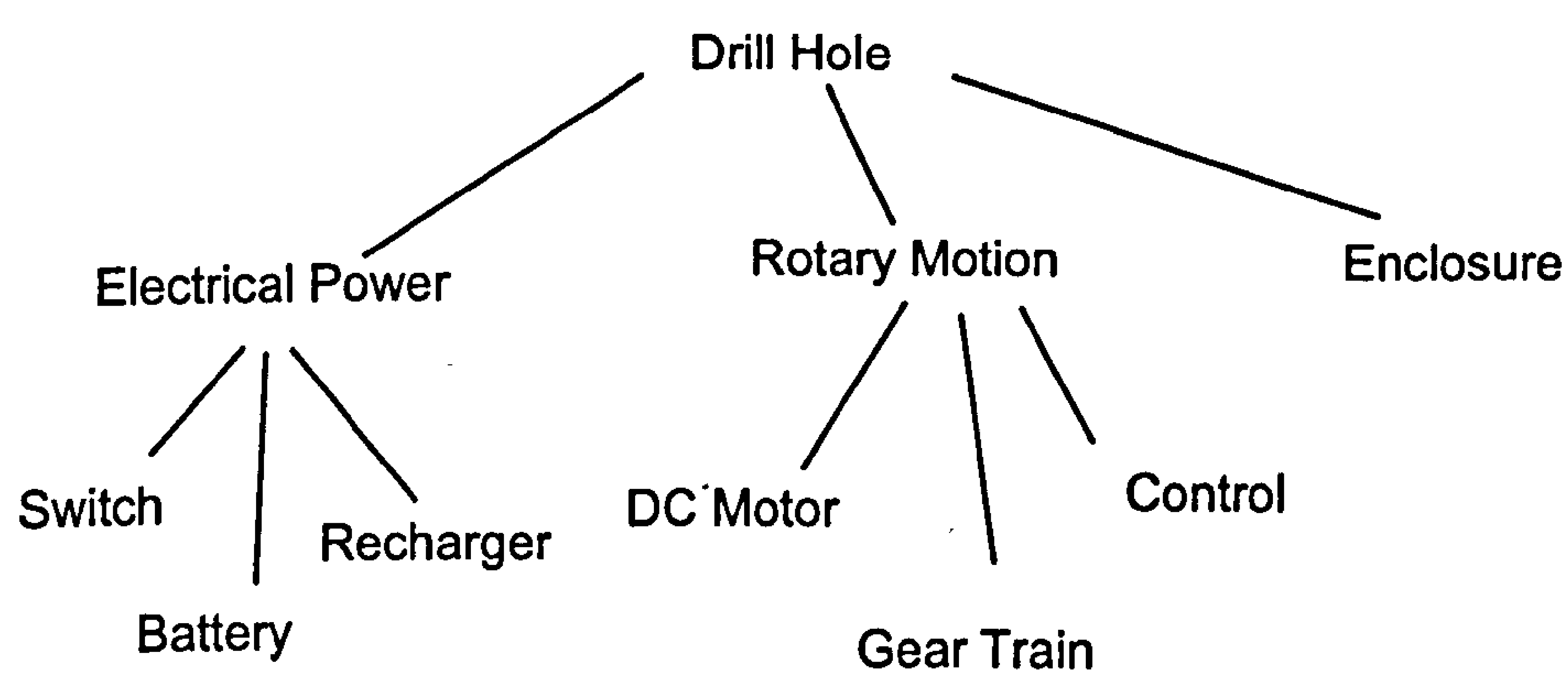


Figure 2-10: Form tree

Feng et al., (1998) have reviewed most of the models mentioned above and have concluded that they are far from being available for a real industrial application because they do not provide a realistic assessment of manufacturability of conceptual products developed at the early design stage.

2.3.3. Design-to-Cost

Except the development of value engineering a methodology called design-to-cost (DTC) emerged (Vitaliano, 1994). This method aims to ensure that tight cost targets can be met. Design-to-cost deals with the issue of cost reduction at an early stage, during designing. It investigates what would be the best way to reduce the cost of a component or system without diminishing too much the overall performance of it.

Vitaliano emphasises that is not correct that "product cost responsibility belongs to production, while development cost control belongs to engineering". In design-to-cost it is important that the designers give cost the same consideration they give to performance and schedule (Williamson, 1994). This is very important for successful DTC, therefore when cost is treated as a design parameter, cost reduction invariably takes place. Obviously, to achieve this cost reduction aim it is necessary that both conceptual and engineering designers have knowledge of how the cost of a component is formed (Busby, 1997). Also the management which is setting the cost reduction target should have information of what would be realistically achievable.

French (1999) argues that the whole subject of costing in design is relatively little developed, considering its great commercial importance. Today, there are still some major issues to be solved before designers can have suitable information which is accurate and timely for costing evaluation. Geiger (1996) mentions that there are three major reasons for this; isolation of product designing from cost information, the lack of suitable tools to give feedback about cost implication, and lastly "inability to integrate the existing but diverse and heterogeneous data of the various functions".

Analysis:

- The author believes that although many of the factional decomposition techniques reviewed have been developed for academic purposes only, the nature of CE and its "real world" application dictate that a realistic approach is used for the functional decomposition. Therefore in Chapter 6 the author will utilise functional decomposition techniques.

- The author finds Kirschman's approach quite intriguing. It is a very structured and simple approach that could be used by engineers. Further more it lets an expert formalise his assumptions based on the four groups (Power, Motion, Control and Enclosure). The author suggests that this method could be successfully implemented to add functions to a product where a concept is quite new. More of this is going to be discussed in Chapter 6.

2.4. Data and Information in Cost Estimating

One of the approaches the author is considering and indeed he follows is the development of a data infrastructure for cost estimating in the automotive industry. For that reason the issues surrounding data, information and communication are reviewed.

Data can be defined as "a basic level component in all information and knowledge, a piece of fact that has no meaning or value until it is structured, analysed, communicated and organised". This implies that information is organised, structured and analysed.

Often it is said that this information is crucially important to a business. Some people (Toffler, 1980) go so far as to claim that information is the fifth resource of the company, after people, equipment, material and capital. Drucker (1969) agrees that "information has become the central capital, the cost centre, and the crucial resource of the economy". Even though some might argue of the centrality of information there is no doubt that information is vital for current automotive businesses. Cassel (1981) adds that information is the content of any meaningful communication. Communication failures cause disruption in a company, therefore communication is important in automotive companies, as these companies are big in size and they have ever changing products (Court et al., 1997).

Suitable information is the content of any communication which allows the creation and the utilisation of cost estimates. Information facilitates the interaction of people, material, equipment and money to reach the profitable and competitive products. Correctness of information is important as poor information can cause multiple problems such as designs which are not optimised for manufacture or assembly, feeble investment justifications, and purchases of overpriced components. Eventually these and other causes may eventually lead to unprofitable products due to higher cost of manufacturing.

2.4.1. Characteristics of Information

The information used in cost estimation is not accurate. The accuracy is a relative matter (Stamelos, 2001). This is because a cost estimate is a probabilistic assessment and therefore involves uncertainty. The decisions are often made on the basis of inaccurate, incomplete or out of date information (Lederer, 1995; Strike, 2001). These decisions may be poor and result in considerable unnecessary expense. As cost estimates are mostly based on estimated information, it is necessary to well understand how these estimates are composed and in where lies possible sources of risks.

The literature (Benyon, 1990; Court, 1997; Lucas, 1997) has identified several characteristics that are required for the thorough understanding of information. These characteristics define what would be "good information". The list below defines the characteristics found:

Accessibility – how information can be accessed
Accuracy – does the information reflect the reality, is it normalised and validated
Breadth – the scope of information
Completeness – does the information provide the user all that needs be known
Form – in what form is the information needed, collected and produced
Origin – source of the information
Relevancy – why the information is needed
Timeliness – related to accuracy and relevancy; after a time information may not be accurate nor relevant

It can be seen from the list that the definition of the information is only a start for the understanding of it. For example the relevancy of the information is important, i.e. why to use the information or what are the limitations when using the information. Also the information exists somewhere and the user of the information needs to know how and where to access it, for this reason information sources are discussed.

2.4.2. Information Sources

There are multiple sources of information for making cost estimates. But even when there are multiple sources of information decision-making during cost estimation is still difficult especially when dealing with suppliers. Also multiple information sources create a problem of variability; different sources can be used to make the same estimates. This variability creates subtle changes between cost estimates.

Cost estimating information can be collected from e.g. accounting databases, similar past work, professional and reference material, and knowledge (Stewart, 1995). French (1999) mentions that conceptual design stage information is often summarised in a sketch or scheme drawing, usually accompanied by descriptive calculations and notes. By the end of the embodiment design, the material that provides information is typically a general assembly or general arrangement, usually together with supporting notes and calculations. Court et al (1993) have identified in more detail sources of information used in manufacturing companies. Their research discovered a very comprehensive list of information sources for mainly engineering design activities. Previously it was mentioned that detailed cost estimation requires information of product, materials and manufacturing processes. It bears close resemblance with engineering design and therefore these sources can be used also for creating cost estimates. Court et al (1993) identified that the information can be internal, external or personal:

Internal Information.
Design has been characterised as a collaborative activity between specialists. The extent of that collaboration is reflected in the diversity of internal information sources used by the engineers. These include: product specification; previous design schemes; existing design reports; other department reports; data handbooks; development and test data; sales data; commercial data; marketing data; manufacturing data; in-house parts catalogues; design guides and service feedback.

External Information.
These included journals and magazines; catalogues; libraries; professional organisations, institutions, the government, design guides and events. One area of particular interest and importance, in the context of this work, is that of information obtained from suppliers. Firstly, catalogues were found to be extensively used to obtain information with six types highlighted: supplier catalogues, agents, competitors, trade, brochures, and data handbooks. Secondly, design guides were

also found to be an important external source of information with the main source used again being that of suppliers. This clearly shows the high importance that supplier delivered information has for the design team. Here it was found that designers use the advice, guidance, and analytical techniques from component or product manufacturers more extensively than well respected independent organisations (institutions, trade associations, etc.). The information obtained from these was found to include supplier and competitor details; availability; product knowledge and trends; specifications, drawings and data; and costing and marketing. Personal sources can be for example colleagues and personal experience.

One interesting observation resulting from this study was that hardcopy and verbal formats are still widely used in transferring information, with the major sources being those of drawings and sketches.

The sources above contain information that is called explicit information or explicit cost drivers, e.g. part dimensions. Roy et al (2001b) has also identified another category of information which contains cost drivers such as design complexity. Due to the nature of the implicit information it has to be derived through analysis. The information sources for this analysis can be historical cost data or data gathered using surveys.

2.4.3. Information Requirements

Cost estimation is not an easy activity within a company; therefore it is usually performed by experienced engineers and technical cost specialists (Aderoba, 1997). They have experience and knowledge on production technologies, analysis methods and engineering economics. Their skills are especially needed when cost estimating outsourced components or design concepts (Bashir, 2001).

Reliable information reduces uncertainty and therefore risks. Access to accurate and up-to-date information helps to avoid making mistakes or misjudgements (Court, 1997; Shehab, 2001). Unfortunately most of the information for cost estimation purposes is incomplete and imprecise and inhibit from making estimates as sensible as possible (Kingsman, 1997). There are several limitations that cause this such as the information may be out of date, inaccurate, or even unnecessary. Also the sheer volume of information might be a problem. Hughes (1996) mentioned that estimators use limited information but they wished to have more comprehensive and explained information if it was easily accessible. The issues are more relevant during the conceptual design as then there is even less good quality information available (French, 1999).

Plenty of information is also qualitative. There is a need for a quantitative way of modelling manufacturing costs so that estimators can make choices based on factual data, not on assumptions or exclusions (Börjesson, 1994; Locascio, 2000). Again unfortunately currently there is usually little quantitative information to aid with cost analysis, thus high emphasis on the expert judgement in the cost estimating. This is a research area that clearly needs much future research by the community.

2.4.4. Information Usage

The information usage can be divided into two parts, the information used by cost estimators and the information used by cost management or other decision makers. As mentioned before, cost estimators need knowledge about e.g. manufacturing processes, manufacturing methods, and practical knowledge from experience. They will use the collected information to find out the component cost and the most influential causes for this cost. These costs can be derived from several sources but they can be grouped, e.g. engineering, design and development, manufacturing labour, equipment and tooling costs (Stewart, 1995). Weustink et al (2000) have identified in detail how different linkages between different groups of product cost (geometry, material, production process, production planning) affect each other. These four groups are tightly interlinked and changes in one group usually require changes in others, e.g. changes in material might require changes in machining which may impose manufacturing schedule changes. In large complex systems like car manufacturing finding out these linkages is not easy.

Cost management uses information to find ways to increase the cost competence, for example by reducing cost. Manufacturing cost of a product can be reduced by minimising the number of parts, designing parts for easier handling and assembly, or selecting better material-process combinations (Gunasekaran, 1998). Overall cost management needs more qualitative information (preferably this information should be based on quantitative data) than cost estimation (Börjesson, 1994). They deal with questions like "what material this product version now uses and thereby how total cost has changed from previous version" or "whether a component should be outsourced or manufactured in-house". This type of information is used on various occasions, namely for managerial decision making and for planning and control (Williamson, 1996). Examples of activities for the former are cost-volume profit analysis, costing for decision making, and pricing. Examples for the latter are budgeting and budgetary control, financial risk management, performance measurement, and standard costing.

2.4.5. Issues in Information Usage

The information produced by cost estimators gives bases for commercial evaluations. For example ABC cost information and piece cost estimates provide information that can be used in decision-making. This information can be valuable but the research has found that there are problems how less technical people can understand cost estimates (Roy, 2001a). The main concern should be to make sure that information used by non-cost estimators or a junior cost estimators is understandable for them. Using information without knowing as to why and how information is selected into a cost estimate decreases the quality of decision-making. This easily leads to potential misunderstandings.

Court (1995) also mentions that the access to information has become complex as there is too much information. It is not obvious what would be the correct source for selecting the piece of information. This overload impacts on productivity and quality of work (Benyon, 1990; Court, 1995). Court (1995) adds that for example engineering designers spend as much as 30 per cent of their time searching for and accessing engineering design information. Because of this designers tend to use the information that they already possess i.e. they use mainly their memory, knowledge and experience (Court, 1995; Court, 1997). Similarly cost estimators are required to use their expert judgement as they are using similar technical information sources. This implies that they do not benefit as much as possible from information produced by others, especially outside of the company.

2.4.6. Cost Information to Support Design for Manufacture

Boothroyd and Dewhurst (1987, 1991) identified the need for early product cost estimates, in order to make better decisions early in the design process. Once the design configuration has been “locked in” it is more difficult and expensive to make changes. They also identified the failure of most companies’ costing systems to get *early* cost estimates. Difficulty in getting early cost estimates is often due to the manner in which costs are handled by standard cost systems. It is only possible to get cost information once a product has been designed, detailed, and a prototype built. By this time, it is too late for "product design for manufacturability;" all that is left is "fine tuning" of the production process to make the part, albeit more efficiently. Boothroyd and Dewhurst criticise some other cost estimating efforts as being misdirected; stating that:

"...there is much interest in having product DFM and DFA techniques available on CAD/CAM systems. By the time a proposed design has been sufficiently detailed to enter it into the CAD/CAM system, however, it is too late to make radical changes. ...A conflict thus exists. On the one hand, the designer needs cost estimates as a basis for making sound decisions; on the other hand, the product design is not sufficiently firm to allow estimates to be made using currently available techniques. The means of overcoming this dilemma is another key to successful product DFM - namely early cost estimating." (Boothroyd & Dewhurst, 1991).

They suggested a simple activity-based costing approach, which was made available in their proprietary software product. The methodology was to capture the main features of a given design, and use a simplified process plan. The product costs were then calculated using known costs for the given processes. The model relies on the basic models of each process being known to the system, in the form of a machine tool database and a material database. These would include processing rates, cost rate for using a machine, and costs of materials. This would be a very good solution for simple items, with well-developed models for the relationship between design parameters and cost. In many industrial-manufacturing environments, there is a significant gap in this knowledge. Unless the company is able to isolate all direct and indirect costs associated with a production process, they are unlikely to have accurate cost data about products coming out of that process. The lack of knowledge in this area has been well documented in the cost management literature. This is one of the motivations to use activity-based costing instead of standard costing, that is, to provide more accurate allocations of overhead costs, and thereby improve the accuracy of product costing. The activity-based costing method seems to be the best way to isolate costs for a particular activity or process. The problem may be that not all companies have the resources, or the necessity, for a complete activity-based accounting system.

Design for manufacturability is a major motivation for this research; a clear need for better manufacturing cost information exists, and it is not satisfied by traditional cost estimating methods.

2.4.7. The use of cost information in manufacture

Different engineering tasks have different information available for generating relevant cost information. In addition, the tasks use different kinds of cost information for different purposes.

In the embodiment design phase, decisions about materials, surface roughness, tolerances, shape, dimensions, production methods, etc. have to be made. Because all decisions are mutually dependent, a decision about one aspect can lower the costs for that aspect while increasing the costs of another aspect. For instance, the selection of cheap material can lead to extra operation steps in order to achieve a certain surface tolerance, which increases the production costs. Several of these dependencies are present. From an analysis of the product design process and its decision making it can be concluded that the costs fixed during product design are caused by the following interrelated cost drivers: *geometry, material, production processes* and *production planning* (Weustink, 2000).

2.4.8. The cost drivers and the engineering tasks

In the design phase, the primary decisions are concerned with geometry and material. For proper decision-making, it is advantageous to have information from other engineering tasks, usually performed later in the product development cycle, like process planning and production planning. Initially the designer can get benefit out of cost information related to geometry and material. If cost information about production processes and production planning were be available, this would be of great help to the designer. Because geometry does not cause costs directly, the designer cannot calculate costs for geometry. A way to solve this problem is to use cost information from products that have been manufactured in the past. The assumption is made that geometrically equal products (of the same material) will cost the same. This method can give cost information quickly because no other engineering tasks, like process planning, are required to generate more information. The designer can estimate the material costs relatively easy when he has access to a material database, which also contains cost information. Another way to solve the problem is to perform other engineering tasks, like process planning, and to use the generated information for cost estimation. The designer must frequently choose between alternative solutions. In the choice between alternatives, the overhead costs are usually less important because they are made anyway. Therefore, only the direct costs are considered in choices between alternatives.

In the process-planning phase, the primary decisions are concerned with production processes. A cost based decision between production processes is difficult because cost information about a process largely depends on the resources that are used. Similarity, based on production processes, with products from the past could be used in this case. When resources are selected, the extent of use can be estimated and costs can be calculated with the appropriate cost rates. The unavailability of a resource can result in the use of a more expensive resource than chosen by the process planner, consequently leading to higher costs.

In the production-planning phase, the primary decisions are concerned with production planning. Usually, production planning is one of the last phases in the product development cycle before production starts. Production planning determines which resources are used and when they are used.

2.4.9. The Role of Communication in CE

"Currently cost estimation and pricing is a much unstructured decision-making process. Much information required for the decisions are incomplete or imprecise. Cost estimators need both knowledge about manufacturing process/methods and practical knowledge from experience. This leads to the need to use rules to guide their decisions, requiring judgements considering many variables". (Kingsman and Artur de Souza, 1997). In large scale organisations or very complex product designs it is unrealistic for one person to hold such knowledge, and could even be argued to be a Commercial liability.

Roy (2001) investigates improving the communication between technical and commercial disciplines within an organisation. This area of research is very novel. The differing requirements of top-down and bottom-up approaches to cost estimating are recognised as being a major cause of concern in the problems that effect costing of new products. The paper backs-up the idea that there are clear industry wide problems that affect the ability of the cost estimator to do a good job and that these are more fundamental than models and methods.

This idea that good communication is the most pressing need to cost estimating success in concurrent Engineering environments is backed-up by Prall et al. in their article from AACE (Prall J. R and Zecher E., 2001). The article explains that the role of the cost engineer is changing and the organisational environment is affecting the work of estimating. A lean production environment is investigated, estimators were deemed to require communication and facilitation skills.

This recognition of the changing role of cost estimating and required skills is being recognised. However the methods to ensure that cost estimators achieve these skills is less well understood and documented.

2.4.10. The need for information management

From the previous section, it can be concluded that decisions of different engineering tasks influence each other. Furthermore, engineering tasks use information from and/or generate information for other engineering tasks. In order to adjust the need for and the availability of information from different engineering tasks, the structuring of information has to be unified and communication between the engineering tasks has to be made possible. When concurrent engineering is applied in the product development cycle, the need for communication increases even more. Concurrent engineering, i.e. the simultaneous execution of shared tasks by separate departments and the control of cooperative decision-making, requires additional tuning of engineering.

The possibility of communication between the engineering tasks is based on both the availability and accessibility of coherent information (Lutters, 1997a). In the automation of the product development cycle, engineering databases play a key role (Billo, 1987). An engineering database can contain geometric, physical, technological and other properties of "technical" objects and the relations between these properties (Billo, 1987). Usually, the engineering tasks require information from multiple databases. Therefore, for the integration of engineering tasks in the product development cycle an information management system is indispensable. In chapter 5, an information infrastructure model will be discussed.

2.5. Modelling Techniques

Cost estimation information exists in the companies, some information is in a written format and plenty of information is "stored" in the heads of the cost estimation experts. This information (or knowledge) is therefore available for the cost estimation research but it needs to be elicited and modelled. The elicitation of knowledge is itself important but organising and presenting the results in a meaningful way is also vital.

There is an enormous amount of different knowledge elicitation techniques. Interview methods are the most frequently used of all knowledge elicitation methods (Cooke, 1994). Interviews can be divided into two groups: unstructured and structured interviews. Unstructured interviews are free-form interviews. Neither the content nor the sequence of the interview topics is predetermined. This type of interview does not require cost estimation knowledge on the part of the elicitor. Therefore unstructured interviews are best-suited for early knowledge elicitation. The elicitor can get a broad view of the domain. The drawback of unstructured interviews is that they produce plenty of irrelevant data (Oppenheim, 1993). Structured interviews differ from unstructured interviews in the extend to which the elicitation process follows a predetermined format. The questions asked can be open or closed. Open questions (e.g. why or how questions) give freedom of the answers and give opportunity to probe, but they are time consuming to ask and analysis of results takes time. In contrast, closed questions take less time but give less information. Structured interviews provide more systematic and more complete coverage of the domain than unstructured interviews (Cooke, 1994). They also enable to conduct interviews in a faster space as the information asked is more explicitly defined.

An even more structured knowledge elicitation tool is XPat (Adesola, 2001). This tool has been used for research conducted by the ICOST project. XPat is a process driven technique; the knowledge elicitation is structured within input, process and output framework. Input is who/what giving information and output is who/what receiving information. Tasks are how inputs are transformed to output come from the process analysis. The tool uses mainly probe questions to elicit knowledge but the difference to structured interviewing is that XPat links these questions to its input-process-output framework. The benefit of this approach is that although it is time consuming besides knowledge elicitation it also develops a process model. Finally XPat facilitates the expert in articulating their experience.

Besides interviewing and XPat techniques, protocol analysis is a useful method for knowledge elicitation (Ericsson, 1984). This technique is based on observing an expert. This expert is trained to "think aloud" while solving assigned problems. The performance of the expert is closely observed and recorded. The value of this method comes from the fact that both physical and mental actions can be elicited. The mental process complements and explains the physical performance. The drawback of this method is that it requires plenty of preparation and time to train the expert.

As a conclusion it can be said that interviews can produce results that are unwieldy and difficult to interpret. But they can provide results in the short time available with the experts. XPat provides a much more structured way for the knowledge elicitation but it is time consuming and requires a trained elicitor. Protocol analysis is based on observation but it also requires special preparation before sessions. The technique is also time-consuming as the knowledge elicited is based on the actions of the expert.

Further analysis of knowledge elicitation techniques will follow in Chapter 3 and the research design section.

2.5.1. Information Modelling

The previous section identified techniques for the knowledge elicitation. Structured interviews do not have a "structure" themselves, as that is defined by the elicitor. This section discussed information modelling and how it links with the knowledge elicitation.

Loos (1998) and Vernadat (1996) mention that information modelling requires understanding what sort of activities people like cost estimators are practising. To have this understanding requires business process modelling (Eriksson, 2000). Business process modelling captures the broad outline of the activities and procedures that govern cost estimation in a company. This modelling enables a better understanding of the key mechanisms of cost estimation in automotive companies. Therefore to model information it is necessary to understand the process which uses this information. This approach is quite uniform. For example information system development tools, such as SSADM (Hares, 1994), and Unified Process (Jacobson, 1999) are using the same business process oriented information modelling principle.

The link between cost estimation processes and cost estimation information are resources (Eriksson, 2000; Luo, 1999; Melao, 2000). The processes can be divided into smaller component, activities. These activities have explicit goals (a reason for existence), a set of input objects and a set of output objects. The input objects are transformed or consumed as part of the process. They can be for example information, such as material rates. The output objects represent the accomplishment of the goals and are the primary result of the process. In the cost estimation they are final cost estimates or subtotals (in detailed cost estimation).

The activities do not access information directly but the information comes from resources. To perform their functions activities utilise resources, such as reports or databases, and it is inside of these resources where the information resides. Therefore it is essential for information modelling to find appropriate resources.

The literature (Bashir, 2001; Eriksson, 2000) suggests that the models help to understand and manage complexity by simplifying details. Therefore it is not necessary for a business model to capture an absolute picture of the business or to describe every business detail. The models should identify resources to the required level so that information elicitation is as thorough as possible.

This is important as cost estimators utilise plenty of expert judgement during their activities therefore detailed modelling of their activities would be time consuming. Zucker (1995) notes that there is a practical problem when modelling engineering knowledge (which is important to cost estimation). The problem is how the information model may support extensions from general-use data to custom data descriptions. The latter requires the addition of very fine-grained information about company or specific products. However modelling this is very time consuming.

2.5.2. Information Model Presentation

Information Modelling is the process of building models of the whole or part of an enterprise (e.g. process models, data models, new ontology's, etc.) from knowledge about the enterprise, previous models, and/or reference models as well as domain ontology's and model representation languages.

No complete enterprise modelling method currently exists and there is serious doubt that it will ever exist. There exists a wide range of model types which can be used to describe aspects of an enterprise. Mentioned below:

- **Descriptive models:** These models are very good for common understanding and communications among people because of their informal, easy-to-grasp, syntax or formalism. Usually, they make use of diagrams comprising boxes, circles, and arrows. Typical examples include entity-relationship diagrams (ERD), SADT (Structure Analysis and Design

Technique), or IDEF (ICAM (Integrated Computer Aided Manufacturing) Definition Method) notations.

- **Formal models:** These models are expressed by means of formal description techniques (FDT) with precise syntax and semantics. Their objective is to provide rigorous system description and analysis of model properties. Examples include models written in LOTOS, Estelle, Z, EXPRESS, etc.
- **Programming models:** Indeed, any computer program is a model which has the property of being an executable model (as opposed to others which are at most computer process able). They must have a formal syntax and semantics formed by their underlying language, which ranges from assembler languages to conventional programming languages and to fourth-generation languages.
- **Analytical models:** These are formal models with a sound mathematical basis. They have been developed to support computations, model property analysis, or performance evaluation of systems. Examples include control models (transfer functions), differential equations, economic and physical laws, queuing networks, Petri nets, and various types of graphs. In some cases, they have an associated graphical formalism for better human understanding.

The intention of the researcher is not to review all kinds of models applicable to enterprise modelling but to present essential modelling techniques that will help him in developing the data infrastructure for cost estimating at conceptual design stage.

After reviewing the literature it was found that there is no single best methodology for presenting information models. The popular ones are IDEF0 (Integrated computer aided manufacturing Definition), IDEF3 and Unified Modelling Language (UML) (Dorador, 2000). Each of these methods has their weaknesses.

IDEF0

IDEF0 is a method used to specify completely the functional relationships in manufacturing environments. IDEF0 enables to model decisions, actions and activities (Wu, 1994). IDEF0 is used to model activities and information flows. It also models the functional relationships and data that support the integration of those functions. IDEF0 abstracts away from timing, sequencing, and decision logic. This also creates its disadvantages as IDEF0 has no time dependency so it cannot model process flows. Nevertheless, it is a powerful tool for static functional modelling (Colquhoun, 1991).

IDEF3

IDEF0 left a need for other methodologies able to capture the sequences of processes and information structures (Mo, 1998). IDEF3 was created for this purpose (Mayer, 1995). IDEF3 can describe activities and their relationships at required detail. IDEF3 has been introduced to model the flow of control and objects within business processes (Mayer et al., 1992), i.e. to complement IDEF0 diagrams with a process model for the enterprise behaviour and, therefore, to supplement IDEF2(IDEF, 2002). The IDEF3 process description language is essentially a diagramming language. The modelling tool for the representation of the diagrams is made by kbsi software called ProSim. Kbsi is a software company providing similar tools for the whole IDEF family (KBSI, 2001).

It is supported by a set of forms to collect requirements and is based on two components:

- **A process flow description; and**
- **An object state transition network (OSTN)** description. Objects are the entities manipulated by processes. IDEF3 defines an object as an abstraction of a real-world entity which intervenes in a process description.

Process Flow Description

IDEF3 makes use of four essential types of constructs to describe processes:

- The units of behaviour (UOBs),
- Junction boxes,
- Links, and
- Referents.

The IDEF3 formalism, although not formally defined, is interesting because it provides the basis for a real and expressive process model. Any kind of process flow can be modelled. Cooperative activities are taken into account although described in a primitive form using relational links. One of the major strengths of IDEF3 is the description of synchronisation mechanisms, either between processes or between processes and their environment.

Limitations include the facts that exception handling mechanisms are not documented; there is no explicit handling of triggering events, and different ending statuses of a process step are not modelled, although they may influence the logic of the process flow. Time is not incorporated and resources are ignored. The model is, therefore, not suitable for simulation, but remains descriptive. Time can be easily added in the form of mean duration associated to UOBs. However, behaviour rules defined by precedence links and junction boxes are not defined in a computer-process able form.

Information Access Diagrams

Court et al (Court, 1995) propose a technique, Information Access Diagrams (IAD), for better representation of the key information sources, and how they are used. Their methodology also identifies the information access routes used. IAD is based on IDEF1X. However this method does not address business modelling requirements, therefore it would be necessary to combine IAD with IDEF3. The limitation is the one of IDEF1X (Zhang, 1996a). IAD does however give a better understanding of what people are doing during their activities.

Unified Modelling Language (UML)

UML is a standard notation for the modelling of real-world objects (Fowler, 2000; OMG, 2001). It enables to visualise, specify and document the elements of a software-ware system. UML offers a standard way to do these activities. It has received broad industry support since its introduction in 1997 and is a standard modelling language nowadays for computer software systems (France, 1998). Although the language is new it is has already become quite dominant and the number of tools for it is growing rapidly. The language has gained even more strength when it was realised that UML is also suitable for business modelling (Fowler, 2000; Eriksson, 2000). UML modelling centres around nine predefined diagrams: Class diagram, Object diagram, Statechart diagram, Activity diagram, Sequence diagram, Collaboration diagram, Use-case diagram, Component diagram, and Deployment diagram. These diagrams provide an extensive set of notational elements for different needs. In the context of information modelling, the correct definition of class diagrams is most critical (Dorador, 2000; Zhao, 1999).

Even UML is not without disadvantages although UML reflects some of the best object-orientated modelling practices; one of these is that UML does not offer semantics precise enough for all uses. The use of UML in nontrivial development projects can be problematic. For example the UML group (UML) is researching more precise semantics for the UML (France, 1998).

2.6. Summary and Key Observations

In the first Section (2.1), the author explains the notion of cost and the possible breakdowns it comprises. The way indirect costs have changed in the last 50 years and that they account for the biggest percentage of the total cost of a product is described. The importance of ABC is highlighted.

In Section 2.2 the author explains how cost estimating and cost management are interlinked and how important it is for information to be shared across the two sectors. The views of researchers and practitioners, with respect to using cost estimating techniques are presented.

The key observations are:

- The importance of CE-C and CE-E working together is established;
- The importance of accurate and consistent information is acknowledged;
- A distinct lack of literature with regards to Information and its sources is observed by the author that needs to investigate further if he is to develop his data infrastructure for the automotive industry.
- The possibility of using detailed, "bottom-up" estimating as the bases of the costing framework is suggested by the author, due to the possibility of standardising estimates for specific commodities.

Finally the costing methods are reviewed. A summary is provided below:

<u>Expert Judgement</u>

- ✓ Is an unscientific and unstructured process that does not capture the rational of the expert when cost estimates are developed.
- ✓ If reasoning behind the cost estimate is unclear then it is not easily possible to verify how accurate or valid the estimate is.
- ✓ Is one of the most widely used methods

<u>Detailed Estimating</u>

- ✓ Is used after conceptual design in the product life cycle, especially during production.
- ✓ The method gives precise results but it requires detailed product and manufacturing process information which is rarely known and accessible during design phase.
- ✓ It relies on continuity and judgement of cost estimator to be able to repeat similar cost estimates in exactly the same way
- ✓ Very dependent on correct information

<u>Marginal Costing</u>

- ✓ A method that splits up the cost into a variable and a fixed component.
- ✓ Useful for making managerial decisions.

<u>Activity Based Costing</u>

- ✓ Relies on the ability to be able to identify the activities that create the product.

- ✓ Provides a more accurate cost estimate than detailed estimate because it enables to distribute the overhead cost more accurately to products who consumes resources.
- ✓ Unavailability of detailed data is an issue. Task level data is not maintained, and summary detail does not allow item-by-item cost tracing
- ✓ High cost for implementing ABC Systems

Parametric Estimating

- ✓ Parametric estimation can be used before having described the product completely and that is one of the reasons for its popularity.
- ✓ It's a black box, as having incomplete information happens quite often and cost estimators have to guess missing parameters.

Analogical Cost Estimation

- ✓ Relies on components having been estimated before.
- ✓ The case-based reasoning (CBR) is one of the most popular of analogical methods.
- ✓ Advantages of CBR are better transparency than using parametric methods.

Target Costing

- ✓ Is as much a technique for profit management as it is for cost management.
- ✓ Although can be used to manage the life cycle cost, it is mostly used during the design and development where most cost impacts are made.

Design to Cost

- ✓ Some major issues to be solved before designers can have suitable information which accurate and timely for costing evaluation.
- ✓ Geiger (1996) mentions that there are three major reasons for this; 1) isolation of product designing from cost information, 2) the lack of suitable tools to give feedback about cost implication, and 3)"inability to integrate the existing but diverse and heterogeneous data of the various functions".

In Section 2.3 the author discusses how value engineering and functional analysis can help monitor and reduce the costs with respect to the functionality of the product. The key observation here is that costing issues have been considered by design engineers and the relevant academic literature, in order to assist designers. There has been little effort in using functional approaches with traditional cost estimating techniques as they would be used by the Cost Estimators themselves. It is the author's intention to investigate this area of research.

In Section 2.4 the author describes how important information is to cost estimators. The key observations are:

- ✓ Information facilitates the interaction of people, material, equipment and money to reach at the profitable and competitive products.
- ✓ Correctness of information is important as poor information can cause multiple problems such as designs which are not optimised for manufacture or assembly and purchases of overpriced components.
- ✓ Cost Estimating are created and decisions are often made on the basis of inaccurate, incomplete or out of date information.
- ✓ Information sources can vary from suppliers to internal manufacturing data.

- ✓ Also multiple information sources create a problem of variability; different sources can be used to make same estimates. This variability creates subtle changes between cost estimates.
- ✓ Reliable information reduces uncertainty and therefore risks.
- ✓ The information produced by cost estimators gives bases for commercial evaluations.

In Section 2.6 the author describes information modelling techniques in order to identify suitable tools for his study.

- ✓ The key observation is that the models help to understand and manage complexity by simplifying details. Therefore it is not necessary for a business model to capture an absolute picture of the business or to describe every business detail.

In summary, the author has presented a structured account of the costing techniques used by commercial and engineering discipline within cost estimating. The importance of information and how it is communicated across the disciplines is also observed.

The author identified that there is a lack of research with regards to the type of data and information that is necessary in order to perform cost estimates for a specific industry. It is his intention, as mentioned in the next section, to investigate that further and to provide a data infrastructure for the automotive industry as one of his contributions.

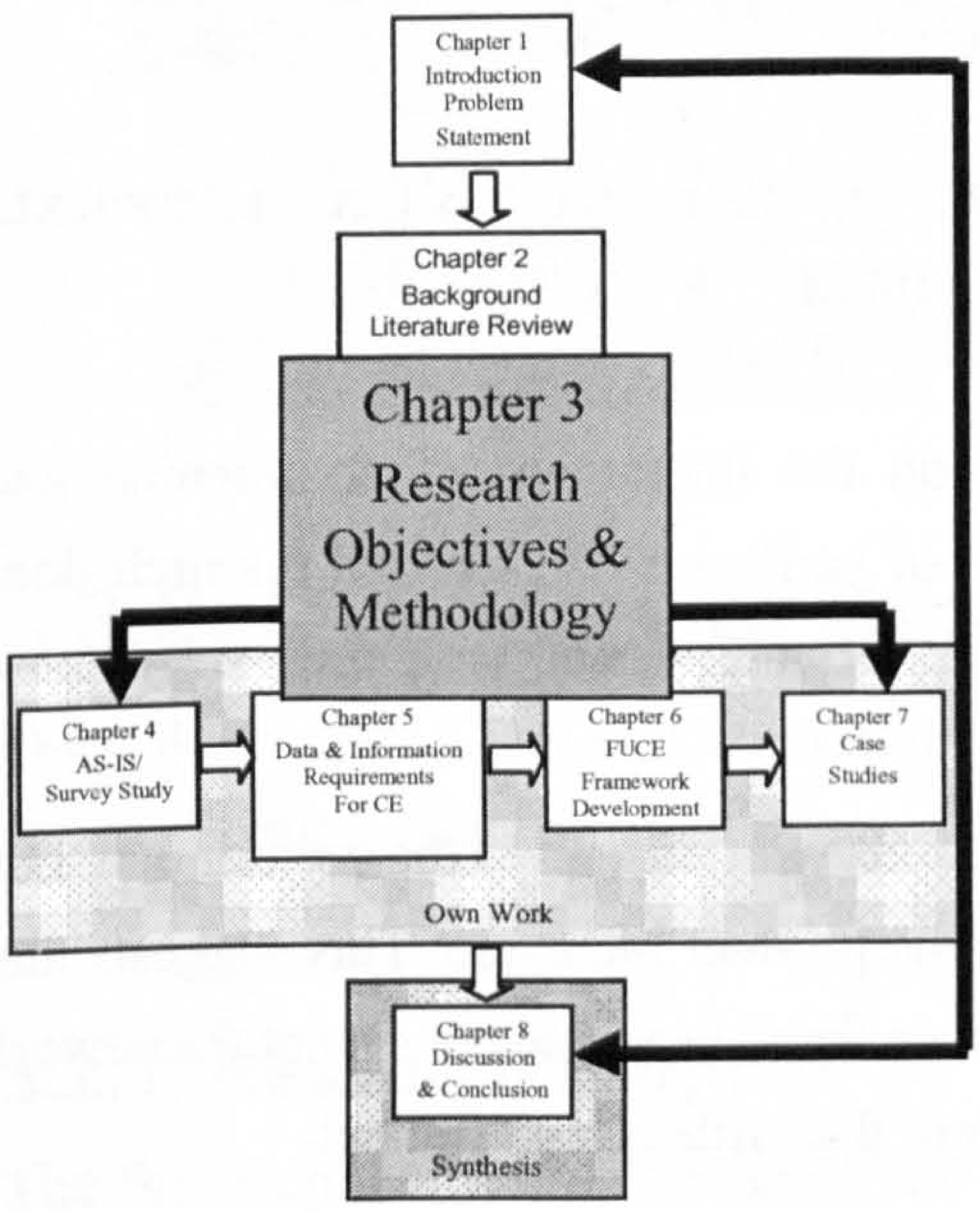
Another gap identified in the research literature is the interaction of CE-C and CE-E and what are the issues surrounding them at conceptual design stage. It is the author's intention to conduct an AS IS study (Chapter 4) that will address these issues and provide some insights to their relationship.

Other issues were also highlighted that are going to be addressed in the following chapters. In particular, the development of a framework that aligns commercial and engineering disciplines within cost estimating at conceptual design stage by identifying a data infrastructure and employing functional decomposition techniques for cost estimating purposes.

To successfully achieve this aim, an appropriate research methodology is designed. The following Chapter presents the development of a research strategy by the author, which he hopes will address the important issues that were identified within this literature review.

THIS PAGE IS INTENTIONALLY LEFT BLANK

3. Research Aim, Objectives and Methodology



In the previous chapter, the techniques and methodologies cost estimators employ for their work were presented. With that, the issues related to the use of data and information within CE was discussed. The key observations from this study were the lack of research in the interaction of CE-C and CE-E and a lack of formalised approaches for improving interaction between them. Based on these key observations, the main research aim and objectives were identified. In order to satisfy them, a research methodology has to be established.

Therefore, the aim of this Chapter is:

Chapter Aim:
To present the research methodology and techniques used to accomplish the research aim and objectives.

To achieve this aim, the chapter will address the following points. In section 3.1, the research aim and objectives are defined. In section 3.2, the different research methodologies are investigated and the author selects a qualitative approach for his research. In section 3.3, the research strategy is presented. The author explains why he chose to perform a survey study at the beginning of his research and why he selected a case study approach to develop further his ideas. In section 3.4, the research methodology is defined. Finally, in section 3.5 the chapter summary and key observations are presented.

3.1. Research Aim and Objectives

The aim of this thesis, stated earlier within the introduction, is:

Thesis Aim:
To improve the internal cost estimating practices at the conceptual design stage within the automotive industry environment.

After the review of the literature, the relevance of this research is put into context.. Here a summary of the research 'gaps' is presented.

- There is a distinct lack of research on the interaction of commercial and engineering disciplines within the area of hardware CE. Current research does not differentiate across industries and organisational structures of costing departments.
- There are different views and contradictions with regards to the costing methods applied by experts at various stages of the product life cycle. This suggests that there is potential for the creation of a more formalised and consistent framework that will assist Cost Estimators to perform their role more efficient.

To address the research gaps the following questions are raised.

- What type of data do cost estimators need?
- What level of detail is needed in the data provided?
- How can product cost estimates be modelled using the existing information sources at the conceptual design stage to improve interaction between CE-C and CE-E?
- Is it possible to help the interaction of CE-C and CE-E at the conceptual design stage?

By answering these questions, the author seeks to address the lack of research related to the data requirements for cost estimating of complex hardware products in the automotive industry. Furthermore, the author tries to establish if it is feasible to develop a model that conveys both the product functionality and the cost estimator's expert judgement. In this way he hopes to create a more structured, formal and reusable approach in developing cost estimates at the conceptual stage of design. To guide the research process the following objectives were set:

- To identify state of the art research in CE and related areas at the conceptual design stage across different industries.
- To assess the cost estimating practices in manufacturing industry and the challenges that organisations face across their commercial and engineering groups at the conceptual design stage.
- To model the interaction of activities and processes of the cost estimating department within the automotive industry, the associated information flows and to specify data and information requirements for CE.
- To develop a structured and consistent CE framework that will improve interaction between CE-C and CE-E.

3.2. Overview of Research Methodology

Once the research aim and objectives are defined, the next stage is to consider the future research strategy or approach that would be used.

3.2.1. Research Purpose

The first step that should be taken into consideration is the purpose of the research. Robson (2002) defines three different kinds of purposes for carrying out research: exploratory, descriptive or explanatory (Table 3.1).

The previous chapter concluded by identifying the need for research into the commercial and engineering aspects of cost estimating. As this is an area that hasn't been researched enough, there is not a lot of public information about this concept and all the issues related. For this reason it was decided that the approach for the research is the *exploratory* one, based on qualitative research. The research strategy will be described in more detail in section 3.3.

Table 3-1: The purposes of research (Robson, 2002)

Exploratory	This has the aim of analysing a new or unknown subject, asking questions in order to collect information about it. As the subject is new, it is not possible to collect quantitative data. Therefore, usually the data collected are qualitative data.
Descriptive	This has the purpose to provide a profile of an established situation, requiring a substantial knowledge of the situation. The required knowledge allows the researcher to select the kind of data that he needs to collect. The data collected can be both qualitative and quantitative.
Explanatory	This gives an explanation to an existing problem in more situations, usually in the form of causal relationships. The data collected can be both quantitative and qualitative.

Exploratory research requires to examine what theories and concepts are appropriate, develop new ones if necessary and whether existing methodologies can be used. It involves pushing out the frontiers of knowledge in the hope that something useful will be discovered (Phillips, 2000)

3.2.2. Quantitative and Qualitative Research

Aliaga and Gunderson (2002) defined quantitative research as "explaining phenomena by collecting numerical data that are analysed using mathematically based methods (in particular statistics)". Quantitative research involves counting and measuring of events and performing the statistical analysis of a body of numerical data (Smith, 1988). The assumption is that there is an objective truth existing in the world that can be measured and explained scientifically.

The main strengths of the quantitative approach are objectivity and reliability Matveev (2002). Following the original set of research goals, it is possible to arrive at more objective conclusions, testing of the hypothesis and determining the issues of causality. Reliability of data is achieved due to controlled observations, laboratory experiments, mass surveys, or other form of research manipulations (Balsley, 1970). The weaknesses of the quantitative approach are firstly, the lack of information provided to the researcher with respect of the context of the situation where the studied phenomenon occurs; and secondly, the outcomes are limited to those outlined in the original research proposal due to closed type questions and the structured format, and therefore do not encourage the evolving and continuous investigation of a research phenomenon.

Qualitative Research is collecting, analyzing, and interpreting data by observing what people do and say. Qualitative research is much more subjective than quantitative research and uses very different methods of collecting information, mainly individual, in-depth interviews and focus groups. The nature of this type of research is exploratory and open-ended. Small numbers of people are interviewed or a small number of focus groups are conducted.

The main strength of this approach is that the researcher can obtain a more realistic feel of the world that cannot be experienced in the numerical data and statistical analysis used in quantitative research and therefore provide a holistic view of the phenomena under investigation (Bogdan & Taylor, 1975; Patton, 1980). Furthermore, there are more flexible ways to perform data collection, subsequent analysis, and interpretation of collected information (Matveev 2002). The main criticism of the qualitative method is that it is possible to arrive to different conclusions based on the same information, depending on the personal characteristics of the researcher. Furthermore, there is a lack of consistency and reliability because the researcher can employ different probing techniques and the respondent can choose to tell some particular stories and ignore others.

3.3. Research Strategy

There are many research strategies or methods that can be used to collect the data necessary to answer the research question. The method of research chosen depends on the nature of the enquiry. Robson (2000) presents three traditional research methods widely used and recognised: Experiments, Surveys and Case Studies. The characteristics of these are presented in the following table:

The author decided that he had to use two different research techniques for different stages of the project. His first study, presented in detail in chapter 4 was conducted as a survey. The main body of the work was conducted using case studies.

The main reason for choosing a case study approach was the fact that this research is industrially sponsored. This reality provided the researcher with access to "real world" situations and in an environment where CE experts were available for interviews and data collection. Furthermore, as already established in the previous chapters, many of the processes employed by cost estimators are informal and not documented. Only direct involvement of the researcher in the environment would uncover further details.

Table 3-2: Characteristics of research strategies (Robson, 1993)

Experiments	"Measuring the effect of manipulating one variable on another variable. Its typical features are: - The selection of samples of individuals from known populations - Allocation of samples to different experimental conditions. - Introduction of planned change on one or more variables. - Measurement on small number of variables. - Control of other variables. - Usually involves hypothesis testing."
Surveys	"Collection of information in standardised form from groups of people. Its typical features are: - Selection of samples of individuals from known populations. - Collection of relatively small amount of data in standardised form from each individual. - Usually employs questionnaire or structured interview."
Case studies	"Development of detailed, intensive knowledge about a single 'case', or of a small number of related 'cases'. Its typical features are: - Selection of a single case or a small number of related cases of a situation, individual or group of interest or concern. - Study of the case in the context. - Collection of information via a range of data collection Techniques including observation, interview and documentary analysis."

3.3.1. Case-study Strategy

Case studies are widely used for industrial research (Gummesson, 1991). Using a case study approach is a way of verifying or building theory. It can assist in strengthening a conceptual definition or challenge an existing way of thinking. It involves examining a representative instance as a way of seeing whether an existing theory really works, or to generate hypotheses or to examine the consequences of a decision. Therefore the author acts as an explorer who is mapping out and suggesting new areas of investigation (Evans, 2002)

3.3.2. Case Study Issues

Case study is a descriptive method, not an explanatory one. Therefore conclusions about cause and effect relationships are very difficult to draw. Case studies are subjective. Participants are asked to respond t general questions and the interviewer explores their responses to identify people's perceptions and opinions about a specific topic or idea. Therefore the findings are directly dependent upon the skills and sensitivity of the interviewer. Finally, case studies usually involve an individual or a small group and therefore maybe it is not representative of the general group or population. This has the potential effect that important details are left out.

3.3.3. Case Studies and Data Collection

After data has been collected in an enquiry, it has at some stage to be analyzed and interpreted. A common approach is for this to take place after all the data are collected. However, sometimes, and particularly with case studies, it makes sense to start this analysis and interpretation when you are in the middle of the enquiry. This analysis is necessary as "raw" data by itself is not sufficient for useful conclusions (Robson, 2002). It is often the case, during the analysis of the data that ideas and useful interpretations are developed (Burns, 2000)

Data is usually collected in the form of document, archival records, interview transcripts, direct observation, participant observation and artifacts. By using a combination of these data collection approaches, a case study is more likely to be complete and credible (Yin, 1994). Furthermore, by cross-checking data from multiple sources, the study becomes more credible. It is important to note, that during the data collection, the research questions that initiated the case study maybe are modified due to new key factors that emerged during the data collection.

3.3.4. Validity

Validity is concerned with whether the findings are "really" about what they appear to be about (Robson, 2002). The main threats to validity are subject error, subject bias, observer error and observer bias. Subject error refers to the possibility of interviewing a subject or monitoring a system at a moment that it does not demonstrate its typical behaviour. Subject bias refers to the possible influence an external parameter, indeed the observer himself, can have on the subject under investigation, as the subject may not respond honestly to the questions asked. Observer error refers to the possibility of the researcher not understanding or not documenting correctly his findings. Observer bias refers to the issues of interpretation due to the interference of his assumptions and preconceptions in the analysis of the data. The author deals with these points in the next section.

3.4. Research Methodology

Based on the research strategy considered so far in this chapter, a research methodology is proposed in Figure 3-1. The methodology itself can be divided in three phases: 1) Research strategy development 2) data collection and idea formulation 3) data analysis and validation (Rush, 2002).

In the strategy development phase, different approaches to research were considered such as quantitative and qualitative approaches. The decision was made to use a qualitative approach. At this point the different research strategies were considered (see table 3-2) and a case study strategy was chosen. Further analysis of how to perform case studies took place in order to make sure the best utilisation of this technique.

During the second phase, the different data collection approaches are considered. The researcher, having made some decision about *what* he needs to know and *why* he needs to know it, and similar decision about *where* and from *whom* he is going to get the information, the remaining major question is how to get this information (Robson, 2002). Since an exploratory approach was decided (see section 3.2.1), very general research questions and a weakly defined sampling strategy is used.

As already mentioned in the previous section, there are issues that need to be addressed in order to ensure the validity of the findings. In order to achieve this, the author decides to:

- Prolong the process of data gathering in the costing departments. This will allow the author to become accepted by co-workers in the company and will reduce the subject bias. It will be more likely that the information provided will be objective and not what the subject thought the author wants to listen.
- Employ the process of triangulation by using a variety of data sources as opposed to relying solely upon one avenue of observation. The same approach is taken by also engaging with more than one expert in the costing department.
- Maintain a collaboration on the interpretation of the data with the people who provide it.

- Complement the file of materials from the actual site with additional document support that can be audited.
- Consult with colleagues in the costing department before composing the final report, in order to establish validity through pooled judgement.

For instance, the author arranged during the development of his AS-IS study, to spend from a couple of days to a week within the costing departments. The author made sure to get in contact with as many specialists and to triangulate the information he was receiving with at least another colleague who was performing a similar function. Furthermore, any available documentation that could prove the arguments of the expert was also audit.

The author also continuously reviewed the literature during the case study period in order to ensure that the ideas and methods developed from theory related well to an industrial environment. Through a combination of case study results and literature, the data infrastructure (see chapter 5) and the idea of the functional-based model were formed (see Chapter 6 and 7)

'Data analysis and validation was the last step of the research methodology. The researcher used semi structured interviews with the experts, not only from the industrial sponsors but also other companies, from similar and other industries. This ensured that the data infrastructure developed was valid to a wider domain than just the sponsors. The results of this study are discussed in chapter 5.

The AS-IS survey was used to develop the functional-based costing model (Chapter 6). Experts were interviewed from both the automotive and the aerospace industry. Its validation was performed both with the sponsoring companies and another automotive company (chapter 7). The results are presented in chapter 6 and 7. In the final chapter the research contribution and the conclusions are discussed.

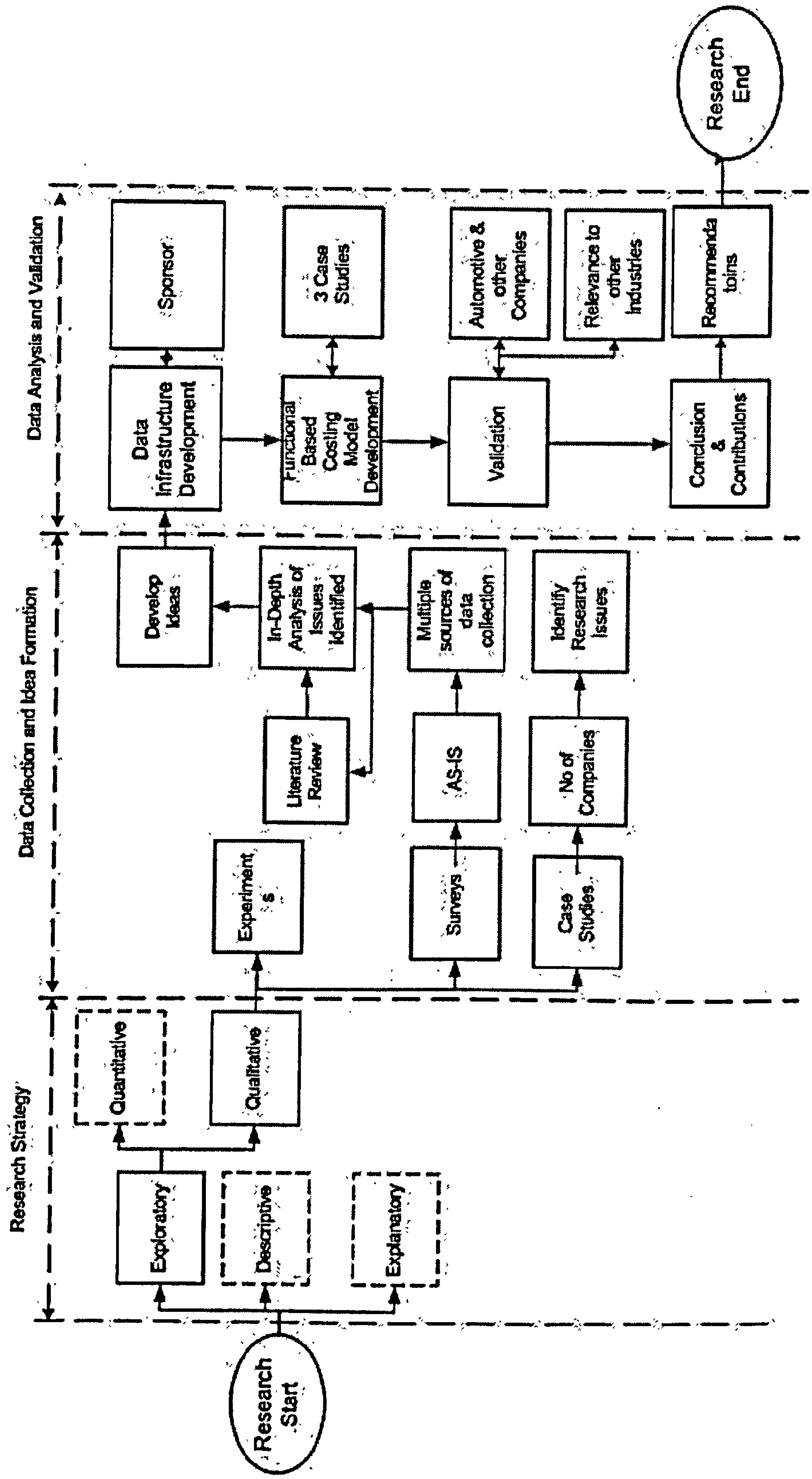


Figure 3-1: Research Methodology

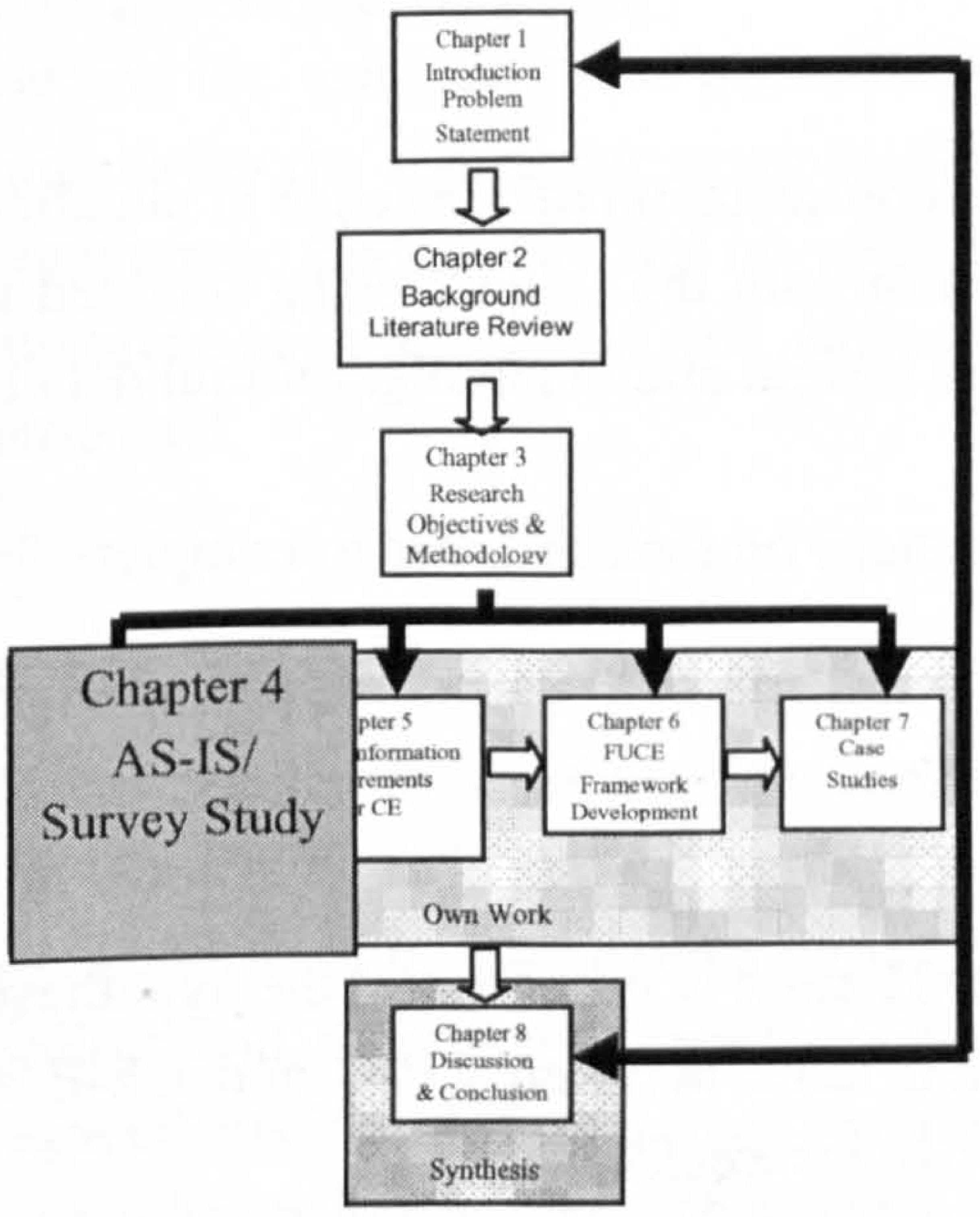
3.5. Summary

In section 3.1 the research objectives were discussed. To achieve these objectives, the author reviewed the different research methodologies in section 3.2. A qualitative approach was chosen. The author decided to use a survey approach in the beginning as he needed to review a wide selection of organisations. Then a case study approach was chosen as the industrial sponsors provided a favourable environment for this. Therefore in section 3.3 the issues of case study research are discussed. Finally, in section 3.4 the research methodology was presented, the author explained how he tried to minimise the risk with regards to the validity of the results.

In the next chapter, the findings of the survey in interactions between CE-C and CE-E are presented. The research methodology described in this chapter lead to the identification of the problem under investigation and more importantly explained how commercial and engineering disciplines within CE do not communicate with clarity due to their mismatched focus.

THIS PAGE IS INTENTIONALLY LEFT BLANK

4. Cost Estimating Survey: AS-IS



In the previous Chapter, the research methodology presented by the author concluded that a combination of survey and case study research was the most appropriate method to satisfy the aims and objectives of this thesis. Within this chapter, the author discusses the initial survey (AS-IS) conducted with the use of questionnaires and semi-structured interviews.

In chapter 3 (methodology) the researcher stated his assumptions that CE-C and CE-E face communication issues and that best possible practice was not carried out. This survey is necessary in order to validate the hypothesis, and if true, to highlight the potential problems that arise.

Therefore, the aim of this chapter is:

Chapter Aim:
To examine the current CE practice within industry: to examine thoroughly the costing processes utilised and the interface between CE-E and CE-E in the overall costing of a product at conceptual design stage.

This Chapter details an AS-IS study for the automotive industry with emphasis at the conceptual design stage. In total, five automotive companies are investigated. In order to expand the possibilities of application of the research and to investigate if there are differences across other industries, the author interviewed also nine other organisations.

In section 4.1 the author describes the methodology used in order to conduct the study. A questionnaire was developed to support the interviews conducted with the cost estimating experts. Section 4.2 presents the results of the study. Various observations were derived from the company visits. The points highlighted include commercial and engineering activities within cost estimating; the perceptions of each others role and the detrimental effects of common misconceptions throughout different organisations. Section 4.3 presents general comments observed through out the study. Finally, in Section 4.4, Chapter summary and key points are presented.

4.1. Design of AS-IS

An AS-IS model, as the name suggests, is a representation of a practice or situation as it currently stands: A thorough investigation into the subject being outlined is required in order to present it accurately, with insight and to highlight useful detail.

In the next sections the author describes the steps he took in order to complete the AS-IS study.

4.1.1. Questionnaire Development

The questionnaire was developed by the ICOST team in order to test the hypothesis of this thesis that there is a communication issue between CE-C and CE-E at conceptual design stage. The survey's objective is threefold:

1. Identifying issues, if any, that exist between CE-C and CE-C across the broad field of 'product cost estimating'. Thus to an extent the questionnaire was generic, designed to be relevant for specialists across areas involved within commercial and technical costing practices;
2. Help to identify the process and data requirements in order to construct a cost estimate (more information on Chapter 5), and;
3. Used as the basis for a semi-structured interview (section 4.1.3) as the experts often raised issues that were not covered by the questionnaire but were also of significant importance for the author to have an overall picture of Cost Estimating.

The questionnaire consists of two major parts: General Issues and the Interface (see Appendix A):

> ➢ The General Issues information is important in order to know how well qualified the cost estimator interviewed is so that the researcher is able to place their comments into perspective.
> ➢ The Interface questions asked how cost estimators are linked with other stakeholders in a company and how CE-C and CE-E see each other.

The focus on interaction between CE-C and CE-E is at the conceptual design stage of the product.

Piloting the Questionnaire

Before the team sent the questionnaire out to be completed, it was reviewed initially by the sponsoring companies and some experts within the cost estimating community. Sections of the introduction and the layout of the questionnaire were modified accordingly, as and where necessary, until a satisfactory version was produced.

4.1.2. Target Audience

It was decided to target specific companies and to utilise the contacts available to the University and from the corporate sponsors of the ICOST project. The experts were contacted by phone or by e-mail in order to introduce them to the theme of the project and to request them to complete the questionnaire. In many cases the respondents decided that they would prefer to answer the questions with the researcher being present. This was particularly convenient as the author had the opportunity to expand on his research questions on an 'as required basis' from the initial focus of the questionnaire. In some other cases the questionnaire was answered either electronically or on paper and was sent back to the author for analysis. In many cases some of the answers needed clarification and meetings were set with the interviewees in each of the companies that collaborated.

In order to have a good representation of the CE practices most of the stakeholders had to be involved in the study. That involved manufacturing organisations in automotive and aerospace, construction and software providers of costing tools.

The companies who were eventually selected for examination were chosen with a selection of criteria, including:

Product

In the scope of work (section 1.4) the author states that the main area of study is manufacturing organisations and more particularly the automotive sector. As a result, a considerable number of companies were interviewed from this sector. Aerospace, construction and cost estimating software developers completed the list.

Size (National/Global)

In general, the bigger the size of an organisation the more difficult the communication becomes between the people. A variation between company sizes was chosen in order to establish if there are any differences in their costing

processes. Availability The biggest issue for the researcher was the acceptance of participation by many of the companies. Questions were raised about the use of the findings and how would they be disseminated to the rest of the participants. Another constraint was the time available the experts were willing to provide for the study.

The above considerations were all taken with a view of collaborating with the widest range of costing groups possible, from a broad selection of differing companies, whilst working within the necessary project resource and time constraints. Table 4-1 presents a categorisation of the companies visited for this study.

Table 4-1: Selection of companies for the study

Automotive	5
Aerospace	3
Defence	2
General Manufacturing	1
Construction	1
Software	2

Due to time restrictions a certain limitation on the number of companies visited was set, this also contributed to the length of most of the interviews which ranged from one to two days. Resource constraint contributed to the fact that all companies examined were either UK founded, or the UK branch of an international organisation.

Thirty five interviews were conducted for this study, involving experts of varying knowledge and experience from a total of fourteen organisations.

The number of people interviewed per company, varied from between one and three individuals. These specialists, though varied in skill, were in general selected from an experienced section of the workforce under examination. To convey the type of personnel from whom the data was procured, a selection of the interviewees is listed, with job title, number of years in company and costing background (Table 4-2).

Table 4-2: List of most common job titles of people interviewed

Title	Experience	Commercial/Engineering
Cost Estimator	12 years	E
Group Leader: Cost Engineer	22 years	E
Senior Cost Engineer	25 years	E
Cost Engineer	4 years	E
Head of Pricing and Estimating	22 years	C
Pricing Analysis Manager	10 years	C
Engineer: Product Profitability Management	10 years	C
Project Manager: Business and Planning	21 years	C
Project Cost Engineering Manager	23 years	E
Financial Manager	23 years	C
Cost Est./finance	21 years	C
Cost Estimators	4 years	E
Purchase	3 years	C
Senior Coordinator	12 years	E
Senior Estimator	10 years	E
Estimator	2 years	E
Proposals Manager	22 years	C
Works Assembly & Test Manager	12 years	E
General Manager, Manufacturing	18 years	E
General Coordinator	2 years	C
Project Services Manager	10 years	E
Managing Director	9 years	C
Cost Engineer	12 years	E

4.1.3. Conducting the Interviews

The researchers opted for a semi-structured interview approach. This enabled the researcher to define the depth of answers provided for different questions and the amount of time and attention given to different topics. This series of interviews was conducted together with the other research member of the ICOST project. The analysis of those interviews was performed separately, each focusing on his/her domain of research.

The primary function of the questionnaire was to support the principle method of knowledge elicitation, which was through personal interviews with the industrial specialists. The interviews were conducted on site, at each company location, by the researchers; they were taped, where possible, to ensure maximum accuracy; and to utilise the information to the best detail. The interviews were conducted in order to obtain the tacit knowledge of the experts; as well as to procure the processes employed for product costing within the company, processes which would be documented both formally and informally.

4.1.4. Dissemination of Observations

The results of this study are summarised in the form of this chapter. A draft of this survey was initially circulated throughout the participating companies, in order to allow any necessary modification to the content, from contributors; prior to publication of the final draft and therefore validating the outcome. This report was subsequently made available to all participating organisations, plus all sponsors of the ICOST project. Due to confidentiality agreement between the companies and the authors the findings of the survey are presented anonymously.

4.2. Analysis of AS-IS Study

Once elicited, the results were analysed by studying the answers given within the questionnaires and the general discussion and points brought out during the taped interviews. The comments and insights revealed through the interviews were subsequently noted and documented. The background, experience and industry of participants were taken into account during analysis. The audio tape information was primarily used to confirm/validate all types of results collected. During the analysis of the data a natural grouping of observations emerged. The author looked at the responses in terms of common, different and specific for each company. Quite naturally a lot of similarities existed between the automotive companies, similarly a lot of parallels existed within the aerospace companies. In the thesis the common observations that where made across the automotive sector are presented in detail. Section 4.3 presents some of the key differences across automotive and aerospace industries. The author also identified many issues and possibilities for further study which he does not present as they do not contribute to the argument and direction of this thesis. Two main groups of observations are presented in this chapter:

1. CE Data, and;
2. CE Internal Practice

4.2.1. Cost Estimating Data

An important observation of the AS IS study was the lack of a formalised approach in regards to a CE database. CE-E produces estimates often based on obsolete data. Wherever there is lack of a specific rate, the estimators assume one based on their experience. Other cases seen throughout this study was the use of different rates for the same labour or machine used within the same department. The reason for that was that many estimators had their own database based on catalogues and brochure provided by machine vendors and suppliers. In many cases these catalogues were very old and did not reflect the current rates of the market. Furthermore, the estimates were not verifiable by other people in their organisation since the rates used were not universal across their company.

Most companies agreed on the point that a common CE database would be beneficial; it was often referred to with slight modification, but generally went along similar lines, of containing general costing information, such as overhead costs, material , labour costs, tooling and so forth. One company examined had developed something among these lines, of software that was exclusive to this organisation. It saved time and resource, and was noted that it reduced the level of expertise required to work efficiently. Concerns expressed towards the usage of this software were that the initial knowledge that went into the development of such a sophisticated tool was potentially open to being lost. This fear was derived from perceptions that a user could have a lack of expertise, but still produce suitable results via usage of this developed tool; subsequently promoting the lack of in-depth knowledge in future commercial activities within cost estimating.

Another company specified a further database, with the aim of keeping track of process, projects (i.e. each specific project taking place simultaneously), ownership of methodology, when personal transferred across projects; with the view of saving time in not having to develop new methods by whomever takes over, or spend time trying to assess and continue with the old, and so forth. This company was a large, manufacturing organisation, and the issues of traceability between projects (to keep track of the numerous consecutively running ones), was something that was a detrimental point of data sharing, communication and costing of projects.

4.2.2. Data Infrastructure-The challenges

During the AS IS Study, it became quite obvious that there are several challenges that shape the working practises used by the cost estimators. Four major challenges were found:

- Lack of resources for cost estimation
- Difficulties to get access to information
- Correctness of information
- Lack of understanding of cost estimation information

Lack of resources for cost estimation

Cost estimators often have to simplify details. That is because finding more detailed information requires too much time and the scarcity of time is a significant issue. Evidently the better the data, it would produce more accurate estimates but there is fine line where more time and cost is spent in finding information than saving costs in another component. The time issue mainly comes from the fact that cost estimating departments in most of the big car manufacturers are quite small in size compared to other functions. As it is not a part of main line business it lacks support. For this reason it is not possible to gain maximum benefits from cost estimates.

Difficulties to get access to information

Above it was mentioned that it is difficult the find information. The information needed for making cost estimates exists, but it is not always readily available. This creates a necessity to "hunt" information. In general it is much more difficult to get information from suppliers than from in-house, although it was also noticed that even within the O.E.M. itself there can be issues on information availability. The availability of the information needed from suppliers varies widely. Some suppliers give required information easily, and some do not want to release it. If suppliers do not want to release information then estimated figures from historical data need to be used.

Correctness of information

The information used for the estimating of supplier's costs is either provided by the supplier or it is estimated. The latter means that the cost data is acquired from internal sources and/or from external, 3rd party sources (consultancy firms, magazines, etc.). In any case the validation of the information is a problem. There are never guarantees that the information provided is correct. Similarly the information taken from internal and external sources does not necessarily correspond with the reality of what are the costs of a specific supplier. More detailed investigation is always needed to verify the facts. However this validation of the information is time consuming therefore the cost estimation always contains the element of uncertainty. The costs estimates are only educated guesses, CE-E are inclined to use expert judgement (EJ) (section 2.2.1). This usage of EJ is quite necessary for doing estimates but it creates another problem. It decreases the transparency of decision making when creating cost estimates. These estimates are created to help other stakeholders in their activities but it is difficult for them to understand the reasoning behind the cost estimates. It is difficult for non-cost estimation experts to understand how a final estimate is derived, and to understand the underlying reasons behind the many assumptions used throughout the process. This creates a communication problem.

<u>Lack of understanding of cost estimating information</u>
Cost estimators work often with other groups within their organisation. The interviewed cost estimators agreed that all major stakeholders should understand the importance of cost information. Purchasing people are important as their decisions have significant cost effects. For example, increasing their understanding on the importance of information gathering is vital to cost estimators, so that they can get the specific information needed for their cost estimates. For that the buyers need a better understanding of what and why cost elements are required. Similarly designers should be more aware of how different design solutions have an impact on costs.

4.2.3. Cost Estimating Internal Practice-Conceptual Stage

Probably the most important activity performed within the commercial discipline of CE is the project preparation phase, as one expert quoted:

> *"From a commercial estimating perspective, an estimate can be requested at any part of product lifecycle. However most effort is expended in the concept phase to generate cost price proposals".*

This activity is very important to automotive companies as it forms the basis of future viable products. Similar approaches are used from tier 1 and tier 2 suppliers in order to get sub-contracts from the OEM's (Original Equipment Manufacturer).

Figure 4.1 depicts the concept stage. Usually a documentation is produced called Cost Information Pack (CIP). A commercial cost estimator circulates to all the engineering functions the specification document of the new product and will require information across all the engineering disciplines believed to be involved with the product, in order to create an estimate. CE-E (engineering functions) supplies the technical and engineering information (detailed cost estimate) that contributes to the formation of an overall product proposal. The CE-E will assess the *product specifications*, and break down the project into activities. This breakdown will be presented to the CE-C. The proposal will thus be collated, with the inclusion of this information. CE-E are the primary experts with regards to this information, as they possess the technical/engineering knowledge required for these types of task.

The CE-C collates all relevant details, including the commercial and the engineering costing information. Once a project had been approved and commenced, there will still be involvement from both CE-C and CE-E on an 'as required' basis throughout product development. It was stated that the commercial specialists would revise estimates throughout the life cycle of the product. More commonly, however, they are expected to estimate areas of the project as and when required, which is dictated as the project unfolds.

The CE-E interact with their commercial counterparts at 'requirements capture' and 'CE stages. Both of these stages require the involvement of the engineering and commercial people. During the first stage, the CE-C will prepare a *product specification* for evaluation. Within the second phase, the necessary requirements for the successful completion of the product are formed, including manufacturing, commercial and engineering requirements. At this stage it was stated that the CE-C will have formed initial budget costs based on the previous products and using accounting techniques. The challenge of predicting costs for a product at this early stage of development heightens when the company is dealing with either a completely novel product (that may be technologically advanced for the time of development to fulfil a niche market), and/or a 'one -off' product like a 'limited edition' sports car. On occasion these cases may not have any other products from which to conduct suitable benchmarking and make revisions. It was recognised that costing knowledge and experience of both the commercial and engineering kind, was necessary to effectively overcome the above challenges.

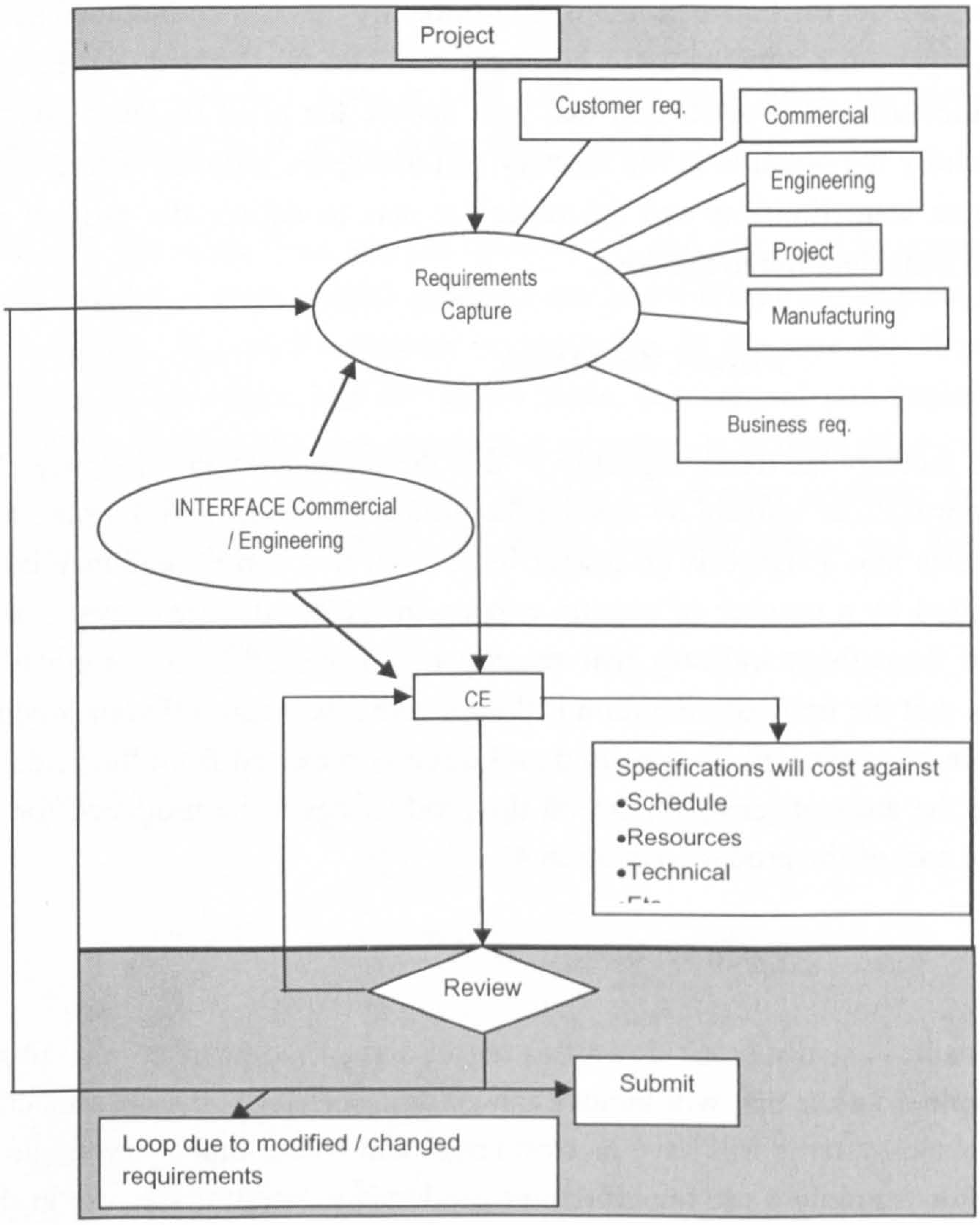


Figure 4-1: Conceptual CE Phase

The key issues that arise during this process and that the experts stated are:

- The *product specifications* and the impact they have in the product cost estimate are not properly documented and understood.
- Because this documentation does not exist, it is almost impossible for CE-E to replicate results or to have correlations of costs with similar products.
- Due to this fact, commercial and engineering disciplines often disagree with the final cost result of a proposal.
- There is a lack of interaction between the groups and that impacts internal CE practice.

4.2.4. Cost Estimating Internal Practice-Target Setting

One point that has been highlighted by most companies has to do with the way cost targets are set for future products. Traditionally this is a commercial activity. In the past, equation 3 dictated that a company will add the profit it desired to the cost of manufacturing a product and that will denote the price of the product. This was especially the practice in the military and aerospace industry where in the past the budgets were limitless and the objective was to deliver the product with not so much consideration to the cost.

$$Price=Cost+Profit. \qquad (3)$$

More recently the trend, arguably, is that the market dictates the price. This bottom up approach, of starting by costing the product, and then building the remainder of the costs into a figure is no longer feasible in this current commercial climate, as specified by a number of costing experts interviewed. Nowadays, it is commonly stated throughout industry that the top down approach to costing is used. This states that the first consideration is the price that you can sell your product, then the margin of profit will be specified and directly removed from the price, which will leave the amount (cost) for which the product has to be produced for. This is the target cost of the product (equation 4).

$$Price - Profit = Cost \qquad (4)$$

Companies usually break down this target cost of the product into subsystems, for example, in a car that will include powertrain, interior body, chassis, etc. Each one of the sub-systems will have its own target and within that every single component too. For example a car manufacturer produced a medium size car in the past that was sold for £15,000 and now has to sell it for £10,000 as this is the price that the competition is charging. That means that a reduction of 30% needs to be made across the vehicle. Therefore the interior cost of the vehicle will have to drop in total 30%, and the same with a single component like a steering wheel.

The above definition was verified by most of the participants. A typical quote came from a manager within the commercial section of a large company examined:

> *"Prior to engineers doing any work on a product, the cost in the form of business trends (-market dictated prices, understanding the customer [which is difficult to asses], how much they are willing to pay, and related issues) ... predicted revenue, target cost, etc ....are all initially assessed by finance"*

Commercial estimators provide the cost targets to the cost engineers within most of the organisations, a process verified throughout this study. Often, prior to any involvement from the engineering sector, the various commercial groups are working towards the product from a cost and price viewpoint, encompassing various issues, including those stated in the former quote.

When the cost targets have been set, the commercial and engineering people will meet to derive the status costs of their products and to see if they are aligned. In the case that the targets are met, the process is concluded. In the case that there is a difference between the target and the status costs, commercial and engineering disciplines start an intense and time-consuming negotiation in order to re-evaluate their costs. It has to be mentioned that the latter is much more common than the former case, as discussed with the experts in this research. Figure 4-2 illustrates that process.

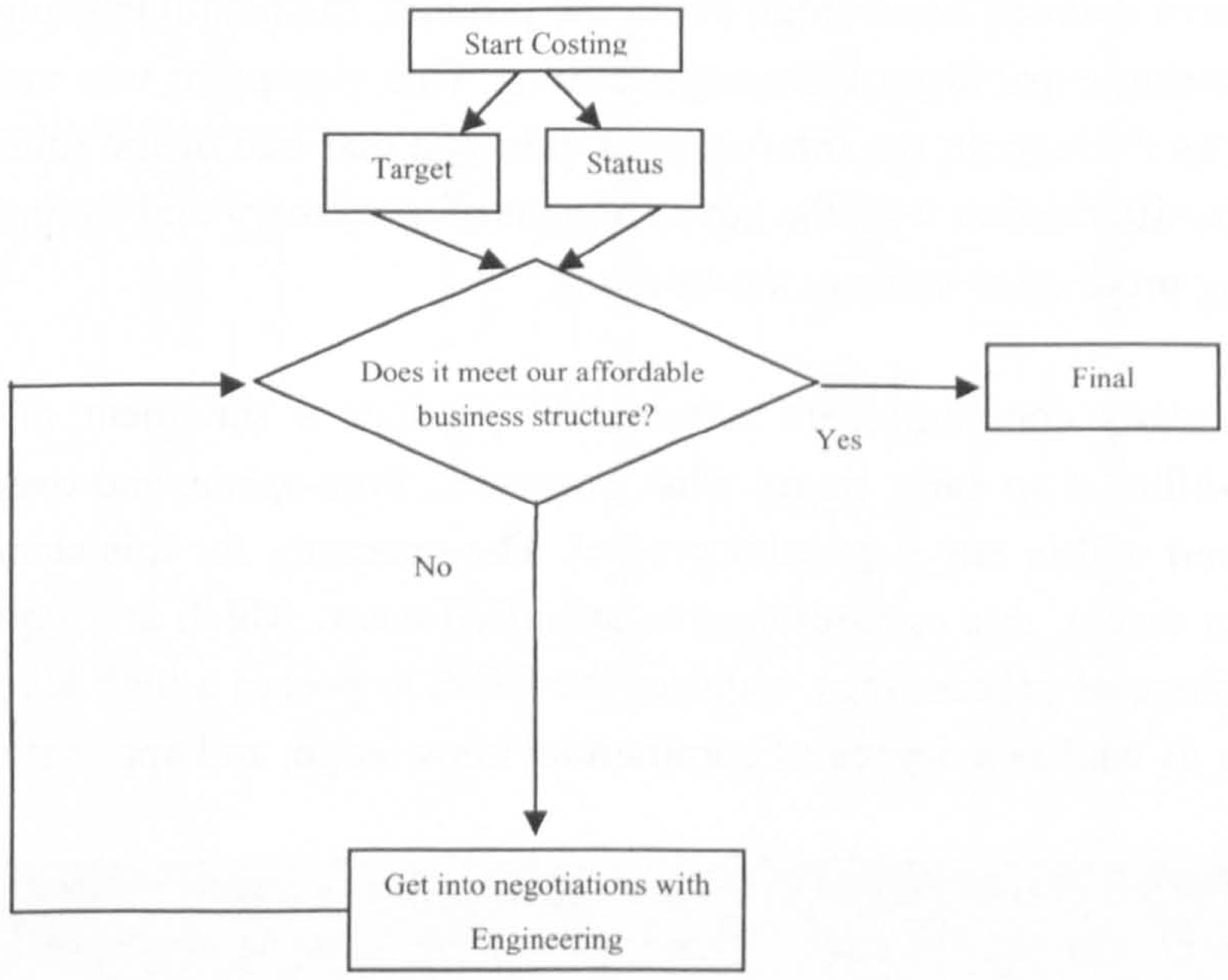


Figure 4-2: Cost Target setting process

Another source proceeded to expand on the commercial group's involvement in CE, by stating that:

"Experienced managers within an organisation, want to generate revenue for the company, and work towards the company's best interest; but this working ethic involves a certain level of overview by the individual concerned. It has

> *been observed that in many cases, commercial people try to drive cost reduction without possessing the engineering knowledge with regards to the product. This creates unrealistic cost targets and creates drifts between us (commercial) and the engineering people"*

Using the example of the steering wheel again, it might be unrealistic to have a reduction of 30% for the steering wheel as the cost engineer who has produced a detailed bottom up estimate predicts that every possible saving has been made based on the *product specifications*.

4.2.5. Cost Estimating Internal Practice-Detailed Bottom up Estimating

A definition of the engineering activity within cost estimating is where it attempts to model the design to manufacturing cost in a bottom up approach for establishing relative costs for different solutions, and methods (section 1.2). Cost engineers need to have detailed knowledge about the product, the manufacturing process, and manufacturing capability of the organisation. This viewpoint was validated within industry, as throughout the interviews it emerged that one of the roles of the CE-E was the familiarisation with the advancement of machinery and technology, in view of keeping production costs to a minimum.

CE-E in many companies are required to produce a statement of work, which outlines -often at an early stage- what processes, time-spans, and overall costs will be involved within any particular project. The necessity for this standard of detail and, to an extent, this commitment to specified costs, which are requested at such an early stage of proceedings, requires the CE-E to posses a high level of technical expertise, as well as a degree of commercial knowledge, and application.

> At conceptual design stage it is very difficult for the cost engineer to create a link between the product requirements (or functions) and the costs. As mentioned in the literature review, the most common approach is to use Expert Judgement in the form of assumptions. The problem with this approach is that the assumptions are not documented and there is no framework in place to re-use them.

Figure 4-3 illustrates the most common approach in constructing estimates in the automotive sector.

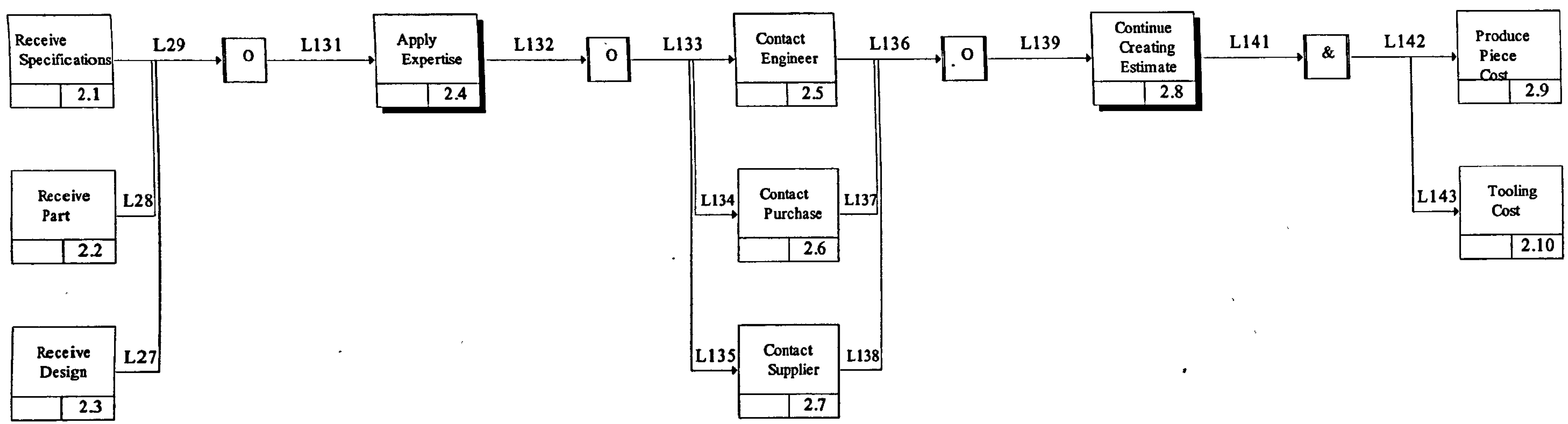


Figure 4-3: Detailed Bottom-up Costing Process

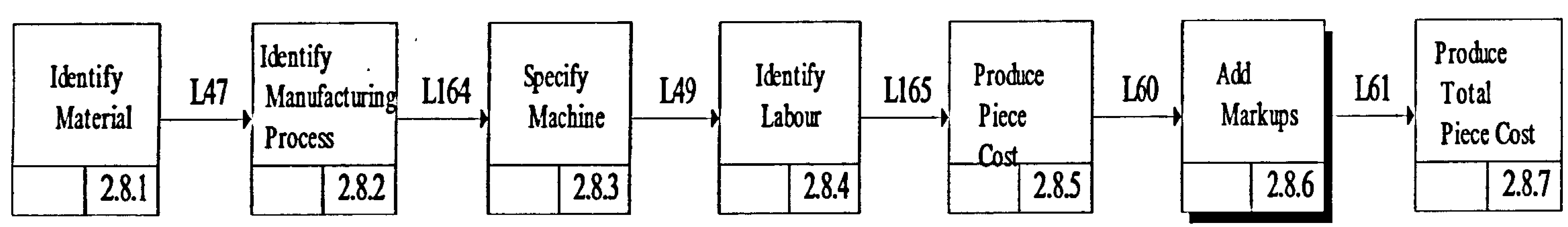


Figure 4-4: Breakdown of section 2.8 (Continue creating estimate)

In order to produce the estimate the cost engineer requires a physical part, a detailed design or detailed specifications. If he decides that this information is not enough, he will try to contact an engineer or the supplier who will be involved in building the specific component. Once he is satisfied with his understanding of the product he will construct an estimate based on the process outlined in figure 4.3.

There are often discrepancies between the cost engineer's earlier quotes, and the acceptability of these figures from the commercial group. This difference of proposed costs, as stated by several industry representatives, comes from the difference of emphasis or importance allocated to the various aspects of the project as well to the different understanding that exist between the commercial and engineering groups.

The main reasons are:

▪ The communication of the product requirements and *specifications* from the commercial to the engineering people is not well established. There is no framework linking the product functions to a cost estimating template.
▪ The data available to the cost engineers to perform their estimates is not of appropriate detail. It was noted throughout the survey that organisations do not have a detailed costing database in order to produce estimates. Data is usually collected from supplier quotes or financial systems within the company.

4.2.6. Perception of Each Others Roles

The previous points lead directly into the perception of each others roles. Disciplines performing commercial and engineering activities within cost estimating are required to work in an integrated manner, as discussed previously. However due to the very nature of these differing disciplines, there can be extensive miscommunication and a lack of fluid interaction. For instance it was explained within several companies that there can often be a lack of trust in the reasoning behind a data request, from commercial cost estimators to the cost engineers. If this request originates from a position of high management, the recipient of this recommendation may assume, often incorrectly as was dictated throughout this study, that the information is required for some sort of 'monitoring' or assessment situation. In this case reluctance to reveal any or all of the information requested in order to reach the final output can often be the case, with data either being withheld, or only bestowed in part. This is due to the fact that the interacting individual may not realise why such detailed technical data is necessary for commercial usage. Also if the cost engineers have over-estimated, and thus not purchased/produced an item at the lowest cost, then the interests of the company will not have been met. Therefore, a defensive attitude will confront a cost estimator who may require a break down of costs from the department, for bidding purposes, or who may, for commercial reasons, require a decrease in value of the engineering cost estimate.

Culture

The culture or 'mind set' present within a number of companies was a major detrimental factor in the integration of the departments. For example, if the general working practice had for several years, been accustomed towards each department focusing narrowly on their own specific area, it would subsequently prove challenging to insight individuals to modify this adopted method of working practice. The promotion of a greater level of interaction, communication and data sharing, between departments was thus a substantial challenge for companies which desired to change their working practice. Most of the experts interviewed reiterated that it is difficult to change established cultures.

An expert related the situation within a medium size company. The situation explained, was with regards to the lack of shared data/information by the relative purchasing department. Within this company, everyone had targets to meet and if people had difficulty meeting these targets they automatically feel threatened within their position. Thus if the purchase department were buying goods at an uncompetitive price, they would generally feel that they would not want this fact brought to the attention of the management, even though the situation that they were currently practising went against the interests of the company. This is highlighting a culture within that department that will focus more intently on keeping cost targets high, in order to met them, rather then on cutting overall costs.

4.3. General Comments

4.3.1. OEM Vs Suppliers & in-house manufacturing

One of the areas that was focused on within this study was the large manufacturing organisations, primarily OEM companies, who were attempting to reduce the cost of their product not solely from in-house production, but also from the supplier chain. A number of these companies had up to 70% of their product being manufactured by external suppliers.

purchased/produced an item at the lowest cost, then the interests of the company will not have been met. Therefore, a defensive attitude will confront a cost estimator who may require a break down of costs from the department, for bidding purposes, or who may, for commercial reasons, require a decrease in value of the engineering cost estimate.

Culture

The culture or 'mind set' present within a number of companies was a major detrimental factor in the integration of the departments. For example, if the general working practice had for several years, been accustomed towards each department focusing narrowly on their own specific area, it would subsequently prove challenging to insight individuals to modify this adopted method of working practice. The promotion of a greater level of interaction, communication and data sharing, between departments was thus a substantial challenge for companies which desired to change their working practice. Most of the experts interviewed reiterated that it is difficult to change established cultures.

An expert related the situation within a medium size company. The situation explained, was with regards to the lack of shared data/information by the relative purchasing department. Within this company, everyone had targets to meet and if people had difficulty meeting these targets they automatically feel threatened within their position. Thus if the purchase department were buying goods at an uncompetitive price, they would generally feel that they would not want this fact brought to the attention of the management, even though the situation that they were currently practising went against the interests of the company. This is highlighting a culture within that department that will focus more intently on keeping cost targets high, in order to met them, rather then on cutting overall costs.

4.3. General Comments

4.3.1. OEM Vs Suppliers & in-house manufacturing

One of the areas that was focused on within this study was the large manufacturing organisations, primarily OEM companies, who were attempting to reduce the cost of their product not solely from in-house production, but also from the supplier chain. A number of these companies had up to 70% of their product being manufactured by external suppliers.

The suppliers (in several instances) seem to have recognised the importance of cost estimating. The reasoning behind this revelation is that suppliers are attempting to procure business from the OEM companies and appearing to be very 'cost aware', as supplier competition is perceived to be high. It was noted that within a number of supplier companies, cost estimating is used as a verification role for contract negotiations with the OEM. A perception is that in order to survive the supplier companies were obliged to improve their costing outcomes, which often meant collaboration with the OEM. One of the commercial activities of CE within an OEM company was to forecast for the purchase department and benchmark the suppliers. Within Supplier companies one of the focal points of the commercial activities within cost estimating is to assist with the organisation of negotiations between the OEMs.

4.3.2. Aerospace vs. Automotive

The major differences that can be noted between the aerospace and automotive industries, with respect to costing practices is the scale which they are working on; and the market which each industry is targeting. The level of integration between the commercial and the engineering cost estimating activities was also noticeably different between the two industries.

Scale of Production

The automotive industry has a few products, but large volume, and to an extent, the aerospace industry is working in the opposite way. This clearly affects the costing processes, and the interactions between them.

Targeted Market

The automotive sectors produce for various sections of the public, and aerospace produce more for governments, generally on a globally scale, and for entire nations.

General Observation

The Aerospace industry has strict guidelines which are enforced by the government- in form of audits that can be conducted at any time for any aspect of the business. The implications of failing to comply with standards and procedure imposed can be serious, and thus the necessity to follow procedure, standards and regulations within this industry, is recognised: this fact is in contrast to observations made across other industries.

The automotive sector however is also accountable for its costing practices with regards to the commercial and engineering activities in cost estimating, but this accountability is towards the private sectors, as opposed to the public.

Differences between CE-E and CE-C

The aerospace industry makes a distinct segregation of the commercial and the estimating activities involved within cost estimating. This is in fact a fairly unique aspect of costing departmental organisation, as revealed from this study. In direct contrast, one of the large automotive companies had quite deliberately, and effectively, merged the cost engineering activities with the commercial.

Commercial and engineering activities within cost estimating practices varied widely between the aerospace and automotive organisations. The automotive tended in many instances, to adopt a more integrated approach towards cost estimating. Aerospace implemented a more segregated structure, with complete separate groups.

Both industries seem to face the general challenge of a lack of awareness and comprehension between the roles of CE-E and CE-C. The difference arises when examining which area primarily interacts with these costing sectors. In the aerospace industry, it is, as previously stated, often a case of estimators, interacting with cost engineers; in the automotive, it was seen more to be estimators interacting with either the finance or the purchasing departments (company specific).

4.4. Observations

Cost estimators are not achieving maximum utilisation from their engineering counterparts. Cost engineers in some cases, are using inefficient methods and over-estimating with regards to time and resource required per project on a regular basis. This appears to be due to a lack of commercial knowledge from these sectors, including CE-E, who may over-estimate in order to set a budget and time allowance that can be met comfortably. This was observed in some of the aerospace companies surveyed. A reason for this mismatch of focus, as revealed by this study, appears to be the *culture* of companies.

It is observed that the cost estimating practice within an organisation needs significant improvement in terms of interaction between CE-C and CE-E. There is a need for a structured approach to CE that will bring the two groups closer.

- There is a need for a framework that will link the product specifications at conceptual design stage with the cost estimating process.
- The method will need to be reusable so that cost engineers will be able to create estimates faster in the future for similar products.
- The method needs to be acceptable and satisfy both the commercial and the engineering groups of cost estimating.
- A data infrastructure should be proposed that captures specifically the requirements of the cost estimating community.
- This data infrastructure should be, if possible, usable with the framework suggested earlier.

The author believes that by addressing the above issues he can provide a common methodology for commercial and engineering disciplines at conceptual design stage for cost estimating.

Based on the above observations, the author will address in Chapter 5 the data infrastructure requirements for the cost estimators and in Chapter 6 the framework development.

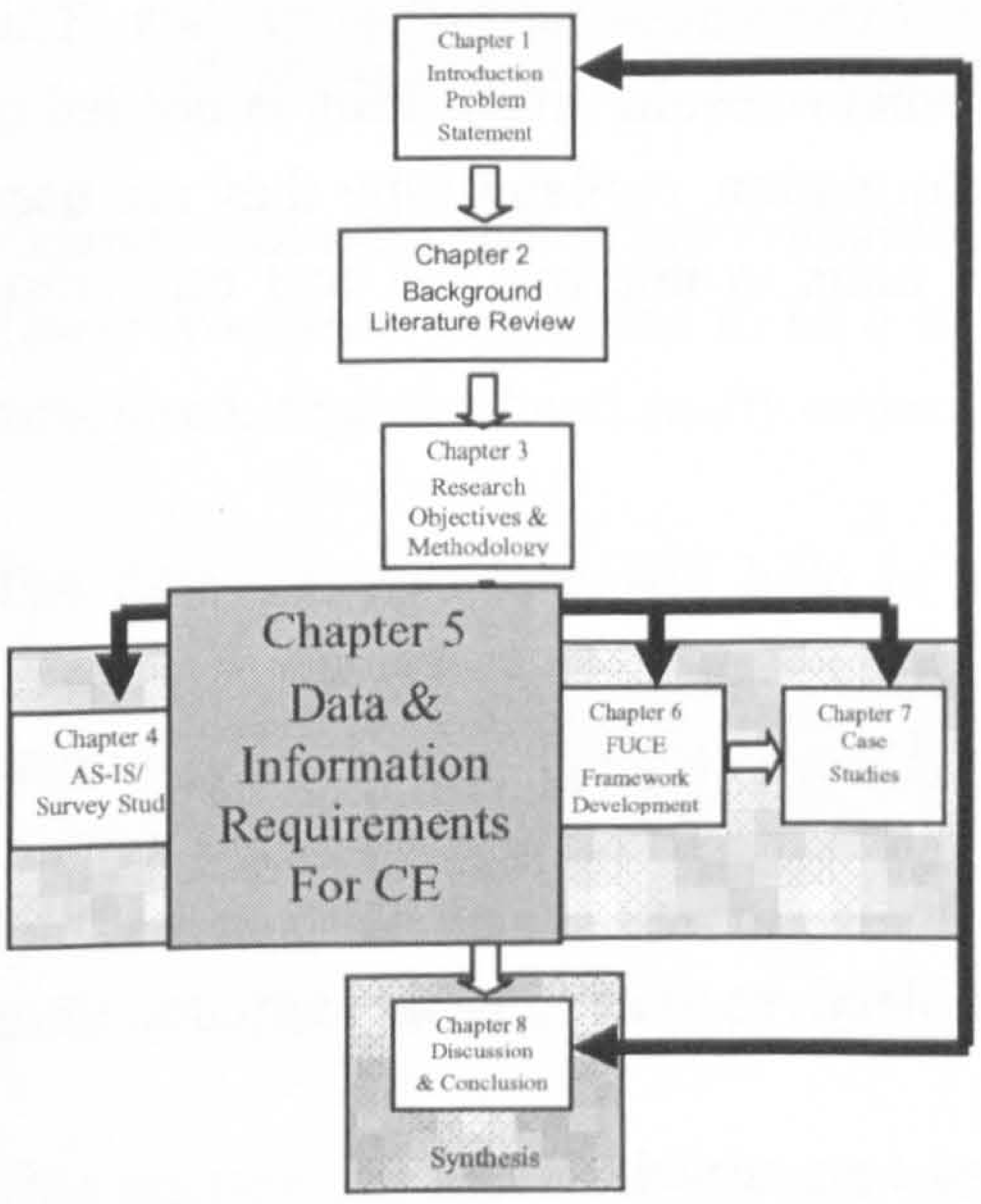
4.5. Summary

In section 4 the author explained why this AS IS study was necessary. In Section 4.1 the proposed methodology was described, a questionnaire was developed and a semi-structure approach to the interviews was utilised. Section 4.2 the main analysis of the study is presented. Detailed estimating, target setting and Conceptual project preparation were identified as the most important point of interaction between the commercial and engineering groups within cost estimating. Section 4.3 summarised some of the general findings across the different industries reviewed. Section 4.4 concludes with the final observation and main points on the finding as identified by this study.

In the following Chapter the data and information infrastructure is presented. Different approached to data collections were used to identify the types of data needed for detailed cost estimates within a manufacturing company. This structured approach led to the identification of the data elements and structure. This detailed analysis confirms and verifies many of the key observations deduced from the introduction (chapter 1) and the literature review in Chapter 2.

THIS PAGE IS INTENTIONALLY LEFT BLANK

5. Data and Information Requirements for Cost Estimating



In the previous Chapter, the author assessed the current practices within CE focusing mainly on the automotive industry and the conceptual design stage. The methodology used for the study described used a questionnaire and semi-structured interviews. Finally the key observations of the study were presented. The literature review and the AS-IS study (Chapter 4) found that cost estimates are important input for various activities in the manufacturing industry.

During the AS IS Study, it became obvious that there are several challenges that shape the working practises used by the cost estimators. Four major challenges were identified (section 4.2.2):

- Lack of resources for cost estimation
- Difficulties to get access to information
- Correctness of information
- Lack of understanding of cost estimation information

<u>Understanding the information</u>

Cost estimates are useful information for various people within businesses but understanding the basis of them is difficult. Not all personnel have the same levels of skill and knowledge as senior cost estimators have. The researchers also found that the information and its sources were not adequate to perform cost estimates. It is equally important to understand what the information actually means, and how the values were chosen when the cost estimate was created. There is clearly a place for a tool that increases understanding on these concepts.

This tool is an information infrastructure. The literature review confirmed that there is no generic information infrastructure for the automotive industry. Indeed there was no published literature identifying the data and information requirements for CE for the automotive industry. This chapter proposes an information infrastructure for information requirements for cost estimation in the automotive sector. This infrastructure provides a partial solution for solving practical problems of people who will create or use cost estimates. The purpose is to bring detailed information to the conceptual stage of design from past experience and historical data. This infrastructure presents in organised manner what relevant information is needed to create cost estimates. It defines pieces of information, explains why they are used and where to find them. This infrastructure aims to improve the cost estimation practice in the automotive industry.

Therefore, the aim of this chapter is:

> **Chapter Aim:**
> To identify data and information requirements for CE and develop a data infrastructure for the automotive industry.

The researcher needs to fulfil the following objectives to achieve this aim, to:

- Develop a common cost estimation process model;
- Identify data and information requirements for CE, and;
- Develop the cost estimation information infrastructure for the automotive industry based on the analysis in the form of a web portal.

By identifying a common process the author can show first of all that the requirements of different OEMs in the automotive industry are quite similar. Furthermore by having identified a common process he can go on and identify the required data and information resources needed for performing that process. This will improve the internal practice of CE.

For a better understanding of the research, the following definitions are added.

> *'**Data** is the basic level component in all information and knowledge, a piece of fact that has no meaning or value until it is structured, analysed, communicated and organised'(Schreiber et al., 2000).*

Data in cost estimating can be considered to be facts regarding floor space requirements of machine, labour rates, etc. that are used in the specification of the cost estimate. Machine and material suppliers create product catalogues with this type of information that could be considered *data* as they contain basic facts about product ranges.

> *'The data can become* ***information*** *when it is organised, structured and analysed in an accessible manner such as a file or database, with the information being interrelated in some way (Schreiber et al., 2000)'*

Examples of information are available as CAD drawings or catalogues of materials. These would be considered to be a source of information because the data is in a structured, organised and easily communicated form.

The data infrastructure will help in solving some of the problems identified in Chapter 1 and Chapter 2 with regards to the information requirements. All the estimates created will be based on the same data infrastructure therefore creating transparency and understanding of the estimates created by other people. Furthermore, due to the identification of resources, cost estimators will be able to audit that information.

This chapter describes the process modelling that was performed within six large automotive organisations and the subsequent data infrastructure derived. In section 5.1 the author describes the approach used to conduct this part of the study, including the questionnaire development and the process models created. In Section 5.2 the process models are presented with the bottom-up cost estimating approach deemed necessary by the author to construct the data infrastructure. In section 5.3 the cost elements as they were identified from the process modelling populate the data infrastructure. Section 5.4 describes the data infrastructure and the hierarchy of the cost elements is presented. Section 5.5 identifies the different types of sources required to collect appropriate information for cost estimating. Section 5.6 depicts the data necessary as it was identified in the form of a web portal which is discussed in Section 5.7. Finally in section 5.8, chapter summary and key observations are presented.

5.1. Design of the Research

The approach taken for this chapter is to identify processes across the different companies. The author believes that if formalised processes are established using process modelling techniques, then can collect the data necessary to perform these processes and define the necessary information infrastructure.

Unlike the initial study (AS-IS) that was performed across different industry sectors, the infrastructure will be developed only across the automotive industry. For that reason six automotive companies were contacted to investigate further the issue of the information infrastructure. For this part of the research Mr. Harri Koponen was a valuable help. Mr. Koponen performed interviews in two of the six companies mentioned and contributed to the development of the web portal as part of his MSc degree (Koponen, 2002).

In brief, the methodology used for this study can be explained in three key steps:

1. The first step is to create a common cost estimation process model for the automotive industry (section 5.3). This model is derived from the work done in the previous chapter, and the processes mapped out with the use of interviews, IDEF3 and X-Pat (see following sections). The information gathering is done by conducting semi-structured interviews with the use of a questionnaire. The questionnaire is used to identify the fundamental steps in the cost estimation process.
2. The second step is to identify the required data and information in order to perform the steps of the process identified above. This step is performed concurrently with the process modelling (section5.4). During these interviews the cost estimators explain the use of these elements for cost estimating. The used elements are identified and categorised (section 5.5).
3. The third step is to identify the different resources where the cost elements can be collected from (section 5.6). These resources contain the information needed for creating cost estimates. These resources were identified mainly from the analysis of the interviews and by the researcher himself.

5.1.1. Questionnaire and Semi-structured Interviews

As with the previous chapter the author found the use of a questionnaire and semi-structure interviews the most appropriate way in conducting his research. Four of the six companies were already contacted for the AS IS report, so getting their cooperation was quite straight forward as the costing experts already knew what was the context of the research.

A questionnaire (see Appendix B) was developed based on the literature review and the analysis of the AS IS material. The aim of the questionnaire was to elicit expert knowledge to create a cost estimation process model that would eventually be used as the basis for the development of the information infrastructure. This questionnaire was developed to support semi-structured interviews. The questionnaire consists of four major parts: Background, CE Process, Cost Information I and Cost Information II:

- The Background information was necessary to know how well qualified the cost estimator interviewed was and to be able to place their comments into perspective. In the cases where the experts had already been contacted for the survey in chapter 4, this section of the questionnaire was omitted.
- The CE Process aimed to discover the general approach to cost estimating within the company, e.g. what cost estimation techniques are used and how cost element information is collected and stored.
- The third part, Cost Information I identified the general characteristics of information used.
- The last part, Cost Information II, was the most comprehensive part of the questionnaire. This part contains semi-structured questions. Questions were designed to elicit information about a cost element for later analysis. The questions were chosen based on the analysis done in the literature review.

Interviews

Thirteen semi-structured interviews were conducted in six different UK based automotive companies, all of them been O.E.M.'s in the UK. The developed questionnaire was used to aid the interviews. Each part of the questionnaires was discussed during the interviews. The cost estimators during questionnaire parts B to D illustrated their activities and information they are using in the cost estimation.

The aim was to identify what information sources were used to create cost estimates.

The last part of the interviews took the major share of the time as this part contained plenty of detailed questions. Part D of the questionnaire was used to collect in depth knowledge of cost elements. For this section the interviewer had developed an initial list of candidate cost elements. This list was used to support the interviews as the last part of questionnaire itself did not contain any cost elements.

The session lasted typically between half to one working day. The participant's background was either commercial or engineering and they were all working in CE. Most of the people were also involved in the AS IS survey of chapter 4 where details of the experts interviewed can be found.

5.1.2. Developing the Cost Estimation Process Model

As mentioned in the previous section, the author tried to identify the processes performed by the estimators. For that he used a process modelling technique known as IDEF3 (see 2.5.3). The primary goal of process modelling is to identify and document what a system does. At first glance, this appears to be a relatively straightforward task. If someone is asked to describe the operation of a manufacturing system by identifying the processes involved, he could likely produce a reasonably comprehensive list. However, he has to consider several other factors when describing what a complex system does. What does a process require to perform its function? What objects participate in the process? What are the precedence and causality relationships between processes and events within the environment? The IDEF3 method (IDEF, 2002) focuses on the abstraction and capture of knowledge about a given real-world system. Such knowledge includes the temporal, causal, and logical relations between processes occurring within the system; the objects that participate in those processes; and the state transitions of those objects. As a result, the method allows you to capture and describe not what happens at this or that particular time in a system, but instead the dynamic patterns that occur again and again among elements in a system. IDEF3 supports this kind of knowledge acquisition by providing a reliable and well-structured approach for process knowledge acquisition, and an expressively powerful, yet easy-to-use, language for information capture and expression. This report assumes prior knowledge of IDEF3 notation.

XPat is a knowledge elicitation methodology used to capture process knowledge (Adesola *et al.* 2001). It can assist in the development of process models such as IDEFØ and IDEF3. This method uses interview techniques and a structure template called 'brown paper exercise' to elicit knowledge from the experts. The XPat approach assisted greatly the author during his data collection phase (Rush, 2002).

The XPat technique was used in conjunction with the answers to the questionnaire to 'capture' the cost estimating process. Workshops were organised with the participation of both experts in the company where possible, and the XPat methodology was followed. A great advantage of XPat was the self-validation of the process where certain 'gaps' in the process itself or in the 'objects/information' associated with it was obvious to the participant to see and rectify. Once the processes were completed, the author described it with the use of IDEF3 and then it was validated by the experts in a workshop.

5.1.3. Data and Information for CE

The identified cost elements were unorganised so the first step was to categorise them. This classification structured the cost elements into logical groups. This categorisation was a consensus that fulfilled major requirements of the automotive companies. This diagram is a tree hierarchy, and the cost elements are categorised into this hierarchy. This hierarchy provided the basis for the creation of the Web Portal which presents the findings of the research. The hierarchy created the needed framework for the pages of the Web Portal.

5.1.4. Developing the Web Portal

As mentioned in the introduction of this chapter providing the information is one thing, understanding it is another. The objective behind the creation of the data infrastructure was to provide explanation for the need of the cost elements and how they can be used. The aim was to gather all the analysed materials together, especially the identified resources, cost elements and the common process model. The cost elements identified during the development of the common process model were the basis for the information infrastructure development. The data infrastructure was developed as a web portal to implement the data and information requirements of CE. After developing the framework, the data templates (web pages) for the Web Portal were created. These templates define each major cost element used in the automotive industry for cost estimating. The combination of the hierarchy and the data templates together created the Web Portal.

5.1.5. Validation of Data Infrastructure

The infrastructure was validated by two cost estimation experts from two automotive companies. The validation provided valuable information for making modifications. It also helped to understand the importance for further improvements.

The next section summarises the general findings from these interviews. It also outlines current challenges and difficulties when doing cost estimation in the automotive industry.

5.2. The Process Models

From the study a lot of activities performed by the cost estimators were identified as they contribute to different groups of people within their organisation. Nonetheless, almost all the estimators agreed that the most important activity they perform, or at least they should perform, is the "detailed or bottom up estimating". The researcher found that some organisations did not perform detailed estimates as they did not possess that capability. The biggest problem they had was the lack of information in order to develop the estimates. If the information was available to them, then detailed estimates could be produced.

A very important observation made by all the companies was that if they had the capability to develop detailed estimates, they could carry out most of the other activities they currently performed much better and provide better support to the CE-C or any other group within their organisation. Indeed because they could not develop detailed estimates they had resolved in other activities within costing.

From the study, two major manufacturing cost estimation activities stood out; *detailed cost estimation* and *benchmarking*. These activities are directly related to piece and tool cost estimating, which are the heart of the cost estimation. These cost estimates are used for various purposes, such as providing support for purchasing negotiations, comparing alternative suppliers, evaluating price competitiveness of current suppliers, cost reduction or value management.

It was found out that although these two models were different-one was for detailed cost estimation and the other for cost management- they had similar requirements in terms of data and information. In the next sections these two processes are described in more detail. In appendix C the author has included all the process models developed for this study.

5.2.1. Benchmarking and Detailed Cost Estimation

As mentioned above two cost estimation processes were selected. Cost estimators make the difference between these two because the initial situations are different. The detailed cost estimation is a bottom-up approach. It collects different cost elements together and sums them up. The benchmarking is normally a part of the supplier selection process. Initially aggregate cost elements are collected (e.g. machine rate) and later during the supplier selection process the cost is broken down into further detail (e.g. machine uptime, machine depreciation and so on). During this stage a detailed comparison is made, that is benchmarking between costs elements provided by several suppliers.

Detailed cost estimation is a basic cost estimation method. During this process all major cost elements are investigated, such as material, processes, labour and overheads categories. Benchmarking is a derivative of that. It compares different costs based on the figures provided by suppliers. These figures are categorised. The categories on the form are developed by using detailed cost estimation thinking. This is not always obvious when looking at QAFs (Quotation Analysis Forms) but when investigating detailed breakdown forms this is clear. This commonality is important because when the cost estimators compare the figures of the different forms they are using their skills to find the best offer. Their skills are mainly engineering thus their benchmarking analysis resembles the detailed cost estimate creation. This logic was clear when the cost estimators explained how they interpret the cost breakdown forms.

It can be summarised that both methods use similar cost elements and they try to break costs down into a desirable level. At the detailed level the author observed that the cost elements started to be quite similar. This similarity of the information and the logic was a positive. For this reason only one model was built. This model is a suitable tool for both benchmarking and detailed bottom-up cost estimating. It contains a proposed logic how well structured cost estimates should be done (detailed cost estimation view) or analysed (benchmarking view) and what information is used during each step.

5.2.2. The Common Cost Estimation Process Model

This section describes the proposed common cost estimation process for the automotive sector. It is based on the detailed cost estimation methodology which is common in the automotive industry. The new model is slightly more detailed in terms of process steps and very much more detailed in terms of information usage of descriptions. Lastly, each step of process is described in detail.

The model describes the workflow used when doing cost estimation in most of the automotive companies (figure 5-1). The model is related to what experts do when generating estimates. The task is a complex reasoning process and therefore it is decomposed in order to make it clearer. This commonality is quite important as in different companies cost estimation processes differ significantly. The model describes the detailed bottom up process. Other approaches identified are presented in appendix C.

General Notes

Resources used during earlier steps are also available during the later steps (e.g. raw material specifications are available when doing the manufacturing process selection).

During the 'gather information' stage the cost estimator verifies that in general all the information is available. During the individual steps more resources might be used.

The process contains cost elements in their "raw format", for organised and categorised representation see section 5.4.

Gather Information

After a cost estimation request has been received cost estimators gather required information for the initial assessment. There is certain material that is useful when creating cost estimates. These are drawings, physical parts and part specifications. At least one of them is needed by cost estimators.

The first option, drawings give the best information for the cost estimation. The cost estimator may get a drawing or several drawing alternatives to compare. From the drawing it is possible to extract dimensions, material usages, and information about surface finishing. However quite often, especially in prototype costing these drawings are sketches therefore they can only give a magnitude of dimensions. The second source of information is a physical part. It is possible to estimate weight and dimensions by measuring it. Sometimes, for example when analysing competitors components, it is not possible to get drawings therefore a part is the only source of information. Part specifications are the third source of information. Normally they contain at least bill of materials and other specific information about the part.

Assess Information

Cost estimators will verify that the possessed information is suitable and sufficient for cost estimation. It is important that the cost estimator understands the reason for the estimate, especially when there are many possible manufacturing process options available. Cost estimators have to understand the product design and suitable manufacturing processes. Engineering designers can help more on technical issues. Purchasing is also a major source of using cost estimation services. The same applies to suppliers, especially when estimating parts designed by them. In this case the estimator normally validates the price of the component.

Identify Material

The cost estimator can identify the material from drawings and bill of materials. If these sources are not available then estimators might be required to use their judgement. The part specifications might provide some hints to choose the material which is suitable for the design intention. Physical parts can also give more information of the material type (e.g. labels on plastic components). The cost estimator needs to know the quantity of raw material and bought out parts (standard or custom made). If the exact number is not available then the dimensions and weight of a part are required. The specifications of materials are needed for both the process and machine selection and for finding an appropriate material rate. Manufacturing processes will produce scrap and the cost estimator needs to take this into consideration by increasing total material cost. Lastly material price volatility has an impact on cost estimation. As the price of e.g. platinum fluctuates rapidly this causes cost estimates to always be inaccurate, therefore material rates need to be verified every time when making cost estimates.

If the cost estimator is experienced, he might contact engineering to suggest cheaper materials that fulfil the functional requirements and the processing methods.

Identify Manufacturing Processes

The correct selection of manufacturing processes requires extensive knowledge from cost estimators. There are two major aspects to be considered, the material to be used and the volume of the production. The material selection narrows the range of possible processes available for the production, e.g. for thermoplastic the injection moulding is a very probable option or for sheet steel pressing might be one of processes to be selected. Another important aspect is the volume of a part needed, for example when the material is brass. If the volume is low then machining is an option, but if the volume is very high then usage of powder metallurgy is a good choice. For the latter there is a high initial cost because the mould is needed.

During the research it was found that cost estimators often consider the identification of the process as a narrowing down activity. The identification of needed process and specifying a particular machine to do the actual work goes together. Normally these two steps are evaluated together. The selection is based on the experience of manufacturing, and this experience is the understanding of the machine cost; therefore the information used during identification of processes is a portion of the information used during the next step.

Specify Machines

The process selection is based on the experience of the manufacturing; therefore it is a qualitative decision. The machine selection however is more based on facts. This selection however requires expertise on manufacturing and the product involved. For example, a question could be, is it cheaper to use a high performance transfer press with four stations, or to use four small individual presses. A more complex example combines both machine selection and process selection. A part such as a plastic inlet manifold could be manufactured using a one shot moulding process to make a fully formed dimensionally correct part. Another option could be to manufacture individual plastic parts then glue them together. Whether both options are suitable depends on the usage of the part, therefore a good specification and knowledge of the subject domain is needed.

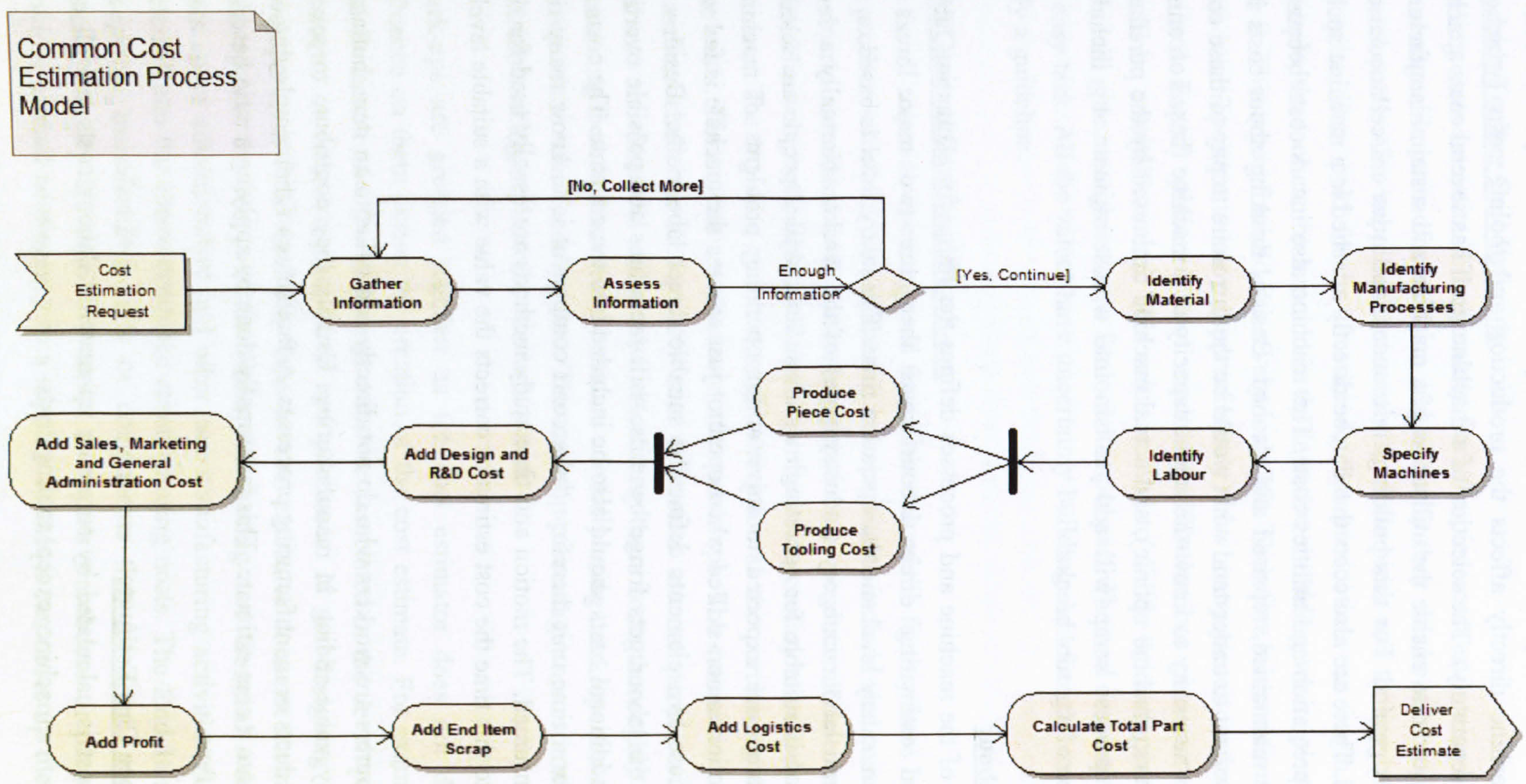


Figure 5-1: The detailed Bottom up Cost Estimating Process

The above machine specifications are mainly needed but the product and the selected machine directly affects the production and tooling costs (which are considered separately). The selection of a machine itself has several costs attached, i.e. costs required to enable the utilisation of a machine and sustain manufacturing capability in general. For this building, insurances, and other miscellaneous cost are incurred. There are also costs that can be directly attached to a machine such as machine depreciation and utilities costs. The machine also incurs costs because it needs to be maintained, repaired and cleaned. Besides thinking about costs it is equally important to understand what would be the fair share to pay of these costs. For this it is necessary to know the actual capacity of a machine (based on annual working hours, machine uptime), and actual machine time used by the purchaser. Finally the process scrap will add realism into a cost estimate, by including consideration of e.g. tool breaks.

Identify Labour

The choice of the machine and processes defines the frame for estimating labour costs. When estimating direct labour costs there are two major areas of consideration, salary level and the operation time. The salary level is based on the skill level and labour category (industry type) of the worker. Normally a semi-skilled person is suitable for operating machines. Semi-skilled people are selected where operators are expected to solve minor operating problems of machines. Labour selection is non-skilled when operator just ensures the machine is fed with material. These two elements define the suitable direct labour rate. Besides the basic wage the labour gets fringe benefits, shift premiums and possible overtime pay. These additional costs should also be included into the estimate. The costs are calculated for a time unit therefore the second component is to know many time units are consumed. The motion and time study methods are usually used for this. In addition to this time the cost estimator corrects the value with a suitable level of allowances.

Indirect labourers are workers who do not directly add value to an item, but assist in some way value-adding in manufacturing. Usually they contribute to several different products or manufacturing processes. A fare share of their employing cost is included into a cost estimate. This is normally done by applying a ratio based on the industry type.

Produce Piece Cost Estimate

The piece cost is calculated by summing up material, labour costs and all cost associated with a machine, except tooling costs.

Produce Tooling Cost Estimate

Tooling costs are estimated separately from the piece cost estimation because tools are changeable parts of a machine and normally they can be used to manufacture several parts. Also suppliers commonly separate piece and tooling costs, as tools are quite often paid for in advance so that production can begin sooner. For example, the tool can be a mould in the injection moulding where plastic is poured into it. This type of mould has a very long life. Therefore when estimating tooling costs it is important to know (approximately) how many pieces can be made using the tool. Expert opinion or tool vendor specification can give more detail what would be a suitable value. This value is used to divide the tool purchasing cost. This will give a rough estimate for tool cost per part. The tool cost estimation is not an easy task. All the values have uncertainty building therefore the results can give only a guideline.

Add General Overhead Mark-ups

So far all material, operating and financial costs of the factory have been covered. To produce a truthful cost estimate it is important to include also costs that cannot be clearly associated with particular operations or products. These costs however exist. The web portal highlights mark-ups that are necessary to include into the cost estimate. The logistics cost is a slight exception as the purchasing decisions can alter costs. These costs are discussed after mark-ups. The estimation of these costs is a clear challenge as normally cost estimators are not people with extensive business and financial skills. Also calculating these costs thoroughly is very time consuming therefore cost estimators are normally using mark-ups that are added on the top of the manufacturing cost. The mark-up percentages are estimated using the decision making explained in the web portal.

Mark-ups are grouped together as the cost estimator does not directly have influence on them during the creation of the cost estimate. For example, **Design, and Research and Development costs** are associated in the development of new products, or improving products and processes. If the designing and product development is done internally then the cost estimator does not normally add any mark-up into the cost estimate. **Sales, Marketing and General Administration costs** cover administrative and other non-manufacturing activities that cannot be included into the above estimated manufacturing costs. The **End Item Scrap** are acceptable manufactured parts or components that for some reason become unacceptable by the time they arrive at buyer's warehouse or plant. The buyer provides a small contingency to a supplier so that it can cover up these additional costs. The **Profit** compensates the business risks of the supplier which is conducting manufacturing activities.

<u>**Add Logistics Cost**</u>

Unlike the overhead mark-ups discussed above the logistics cost are much more tangible. There are many elements to consider when calculating logistic costs. In some companies the logistics people will consider logistics costs. It is very likely that the cost estimator needs to contact logistics experts in order to produce an accurate logistics cost estimate. The information is needed to calculate the cost of logistic from the finished item warehouse to the warehouse of the buyer. First the cost estimator must understand the delivery requirements, e.g. what sort of packaging to use to protect parts. The requirements effectively cause finished part inventory cost when parts are waiting for the delivery. The location of supplier is necessary information for the selection of the supplier as for example the distance and the part type define suitable transportation methods.

An important factor to consider is transportation costs in total. When buyer's goods are emptied it is important to know who is paying the return voyage costs, i.e. is some other company using the service. The same situation applies to packaging materials. The cost estimator needs to know how many times they can be reused if the suppliers keep them.

<u>**Calculate Total Part Cost**</u>

The total part cost covers all the cost incurred. All the costs identified during the previous steps are summed up. This total cost is the estimated price that the buyer should be pay for a particular item. As this method projects the real costs this estimate can only provide is an educated guess what should be an appropriate cost. The supplier might in reality have a lower cost.

5.2.3. Supplier Selection Process

Along with the identification of the resources used, the issue of the cost estimation processes were investigated. The information gathering for them was done by conducting interviews. Part B of the questionnaire was used to identify the fundamental steps of the used cost estimation process. The answers for this section of the questionnaire were compared to the initial AS-IS study (chapter 4).

In the previous sections the author identified that cost expert's estimate mainly the manufacturing cost of suppliers. The author created a model for the supplier selection process based on the interviews with cost estimators. Figure 5-2 shows the major steps of this process. This model increased the author's knowledge of what is exactly done during the supplier selection thus where in the process the benchmarking and detailed cost estimation is performed.

Two steps are discussed in more detail; these are the initial and detailed analysis phases. Manufacturing cost estimation is done during these phases. The initial analysis phase uses quotation analysis forms to compare suppliers. Some companies also have the capability to make cost estimates independently. These cost estimates are used to compare the offers of the suppliers. But in the companies collected QAFs (Quotation Analysis Form) are used to compare the cost claims of the supplier against each other. It should be noted that QAFs are not the main cost estimation tool. These forms are used to find abnormalities in the supplier's quotes. The information contained in these forms is simplified and do not give the clear picture of the manufacturing costs.

The detailed analysis phase is the second part of the manufacturing cost analysis. After investigating quotation analysis forms it is always necessary to acquire more information for the further analysis. During this stage the suppliers are vigorously benchmarked against each other. Supplier factory visits and more detailed cost breakdown forms can be used to gain more information. Both of these activities can become as detail as necessary. The next paragraphs describe the process in figure 5-2.

<u>**Supplier Selection and Benchmarking Process**</u>

This section describes a supplier selection and benchmarking process (Figure 5-2). The most important parts of the process (e.g. QAFs) are discussed in more detail. Other steps are discussed briefly.

Investigation of Potential Suppliers

There can be multiple reasons for a selection of a supplier for a part, such as the launching of new vehicle model. The potential suppliers are scouted by using many sources, including; trade journal, trade exhibits, company personnel contacts, existing purchasing records, and contacting various organisation such as Society of Automotive Engineers (SAE). The selection criteria of the suppliers for the next ground is based on the component needed. At this stage it is mainly engineers who will provide the requirements.

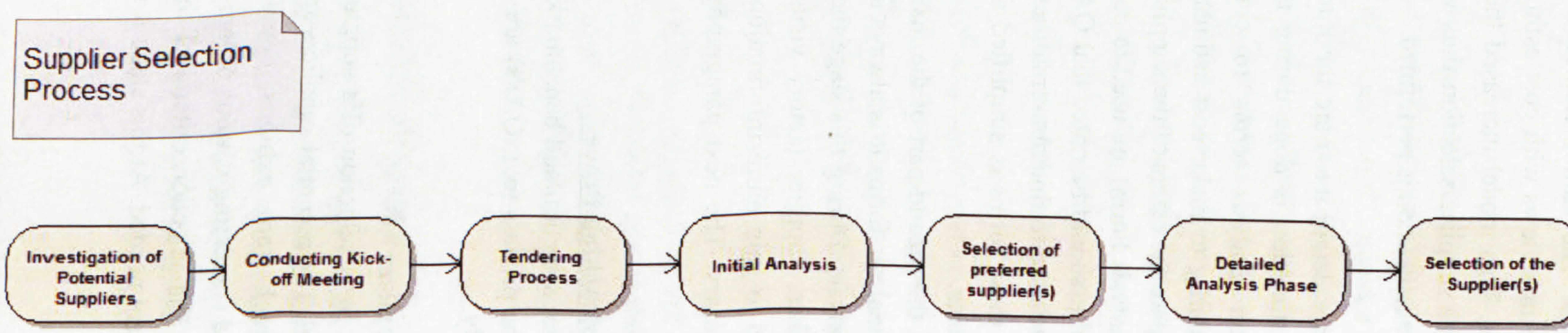


Figure 5-2: The Supplier Selection Process

Conducting Kick-off Meeting

Potential suppliers are then invited to a meeting by the buyer. The supplier presents their company, its services and its capabilities relative to the product or system under discussion. Similarly the buyer explains the requirements for the component and the supplier, and explains and discusses the deliverables and constraints (if applicable).

Tendering Process

After the kick-off meeting a tender pack is sent to suppliers which seem to have potential. The selection of suppliers is qualitative as more detailed information is collected later. The tender pack contains all relevant information for the potential supplier. It illustrates, in the required detail, the information of the vehicle project and/or the product information including:

- The outline and the scope of the project
- The production volume and duration (number of years) needed
- Engineering design overview (can be from detailed drawing to general system arrangements, depending the situation and the supplier relationship)
- Piece Cost Quotation Analysis Forms (QAF's) to the level of detail required
- Tooling Cost QAF's to the level of detail required

The suppliers will provide quotations (to the requested level of detail) to the buyer within the agreed timeframe. This collected information will then be analysed and benchmarked against competitor suppliers. For the manufacturing cost estimation QAFs provide the most important information source.

Initial Analysis

The initial analysis from manufacturing cost estimation point of view contains two aspects; the general supplier evaluation and analysis of the manufacturing costs of the suppliers.

<u>General Evaluation</u>

The general supplier evaluation aims to verify to suitability of supplier for the project, there are several aspects which are evaluated.

- Quality. The quality experts will give their opinion that the supplier is satisfactory for that function.
- Financial structure. The project management will conduct financial assessments and checks to ensure financial performance of the company.

typical information found during these visits will be discussed in more detail in the following chapter.

Final Commercial Negotiations

After thoroughly investigating the supplier manufacturing costs it is possible to settle the final supply contract which contains target costs for parts and tools along with the usual terms and conditions, together with any relevant price escalator agreements or supply volume discounts. From the cost estimation point of view, there are two items that are needed for the cost estimation, they are end item scrap level (maximum amount allowable) and the profit mark-up.

Selection of the Supplier(s)

Once the preferred supplier is selected, using all the above techniques and criteria, the role of the cost estimator will be to work alongside engineering, purchasing and the supplier to ensure best practice is adhered to and that all non-added vale is minimised or eliminated if possible. This may be through the use of workshops and design critiques through to assisting the supplier control the costs of their own suppliers.

5.2.4. Validation

The common cost estimation process model was based on the existing industry validated models (AS-IS study, the common estimating process and appendix C). The development of this model was done by interviewing industry people and investigating working practises. Due to the methodology used it was necessary to validate this model too. The common model, including associated cost elements, was examined by two senior cost estimators. Both were content with the amount and level of detail captured by the model.

5.3. Identification of Cost Elements

Once the costing process was defined, the author could assign data objects to the different steps of the process (Figure 5-3).

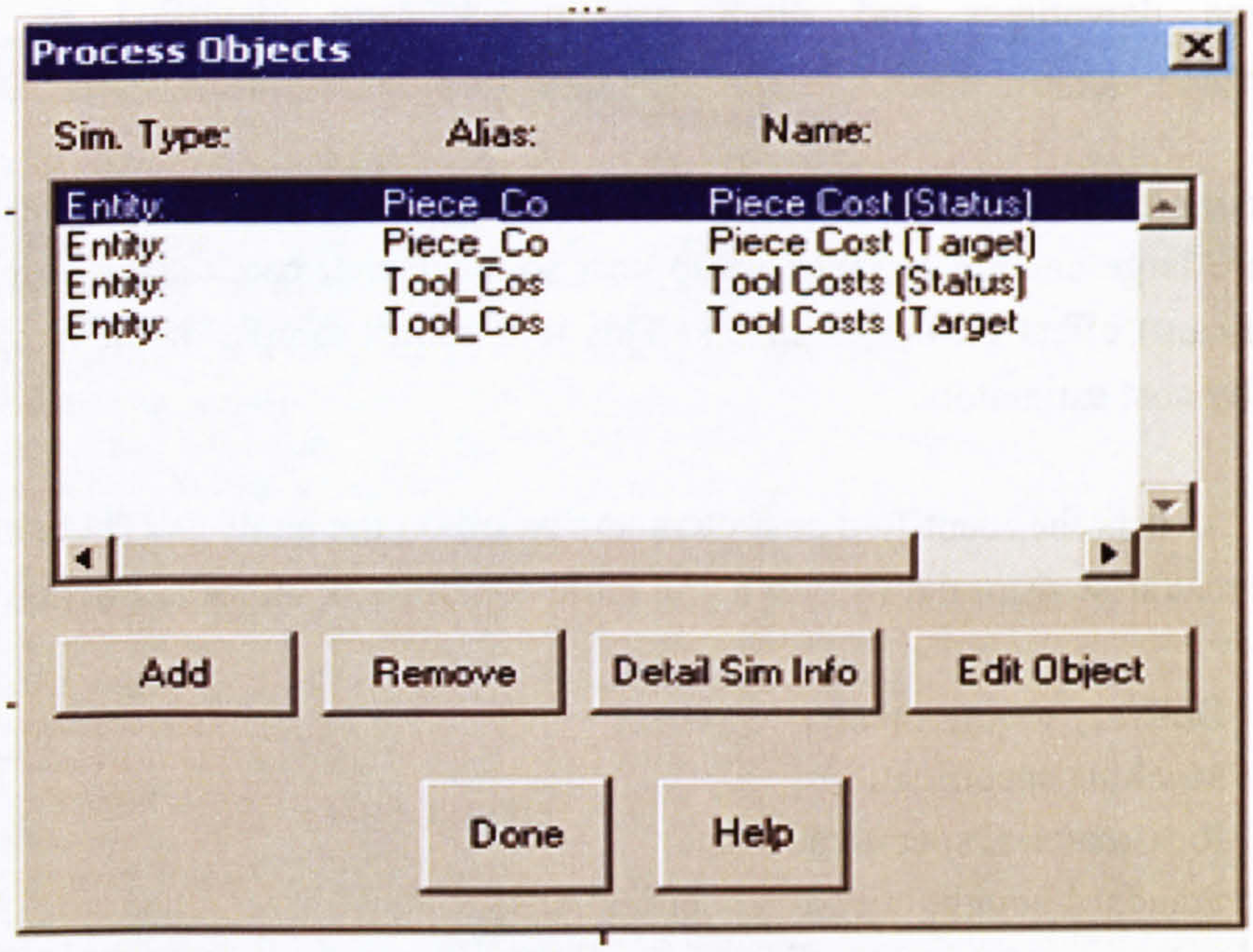


Figure 5-3: Information (objects) related to the Control Model Cost Report activity (appendix C). Picture from KBSI software, ProSim 5.0 (ProSim, 2002)

As mentioned earlier, the cost elements were elicited by interviewing the cost estimators. During these interviews the cost estimators explained the usage of various different information sources for cost estimating. The resources were identified and categorised. This analysis gave the basis for the selection of the cost elements. The comprehensiveness was the base of the selection. Table 5-1 contains all the information items identified during the research based on two criteria:

- The information was considered to be relevant by the cost estimators;
- The information is actually used by cost estimators when creating cost estimates.

At the same time the choice of allocating cost elements to the information resources were made. Normally a cost element was put into a resource if at least three companies identified that as potential source for the information.

During the analysis, it became obvious that only a portion of data available was used. The identified cost elements are a subset of all the information available from identified resources. Only those were included which are important for the creation of a cost estimate. For example, ERP (enterprise resource planning) databases contain massive number of information elements of manufacturing plants, but only machine downtimes and scrap percentages were identified as important information.

An example of left out information is batch sizes. The cost estimators assume that they are large enough to make setup cost so small that batch sizes do not have a (significant) effect on the estimates. This is a good example of the simplification made by cost estimators.

Table 5-1 lists the identified cost elements based on the analysis. There are several points that arise from the list. First, the table contains six important items:

1. Delivery requirements;
2. Machine specifications;
3. Raw material specifications;
4. Standard bought out part specifications;
5. Subcontract item specifications and;
6. Tool specifications.

These groups, technically, contain more information and can be broken down into further detail. For example raw material specification is taken from a drawing (the resource). The raw material specification (e.g. 409 stainless steel) will itself contain information for the cost estimator, important when he is choosing a manufacturing process. However this thesis (which does not contain technical details) assumes that the specifications are "black boxes" therefore are represented as single information elements.

Second, some items are very generic, especially information in the overheads category, such as sales, marketing and general administration costs. The cost is considered as a single value, as it is not feasible for the cost estimator to actually calculate it. These costs are not always collected by cost estimators but domain experts. Cost estimators then use these created values/percentages.

Third, some items are repeated (e.g. 'utilities cost', 'utility quantity' and 'utility rate'). For example, some cost estimators do not consider more than the 'utilities cost', therefore all three items are needed as 'utility costs' is derived from 'utility quantity' and 'utility rate'. However cost elements like 'machine rate' are not included as it is a combination of several cost elements, including it would be over-simplification.

Table 5-1: Cost Elements

Cost Elements	
Annual working hours	Operating time
Bought out part inventory cost	Overtime pay
Bought out part scrap	Packaging cost
Building insurance	Packaging material cost
Building maintenance cost	Package reusability
Building maintenance materials	Part dimensions
Delay allowance	Personal allowance
Delivery requirements	Profit margin
Depreciation of building	Raw material inventory cost
Depreciation of land	Raw material rate
Design, and research and development costs	Raw material scrap
Direct labour category	Raw material scrap resale value
Direct labour rate	Raw material specification
End item scrap	Raw materials usage
Fatigue allowance	Relief
Finished part inventory cost	Rent of building
Fringe benefits	Rent of land
Indirect labour level	Return trip fill rate and content
Infrastructure costs	Sales, marketing and general admin costs
Location of supplier	Shift pattern
Machine cleaning	Shift premium
Machine cleaning materials	Skill level
Machine cycle time	Standard bought out part quantity
Machine depreciation	Standard bought out part rate
Machine floor space	Standard bought out part specification
Machine installation cost	Subcontract item quantity
Machine insurance	Subcontract item rate
Machine lifetime	Subcontract item specification
Machine maintenance	Tool lifetime
Machine maintenance materials	Tool maintenance
Machine purchasing price	Tool purchasing cost
Machine repair	Tool specifications
Machine repair materials	Total part lifetime volume
Machine residual value	Total plant surface area
Machine specifications	Transportation cost
Machine uptime	Utilities cost
Material overhead cost	Utility quantity
Miscellaneous cost	Utility rate
Number of parts per cycle	Volatility of the raw material
Off standard allowance	Weigh of the part

5.4. Types of Data and Information for Cost Estimating

In the previous section the cost elements used in the automotive cost estimating process were identified. That section also presented the common cost estimation process to use elicited cost elements. This section addresses the categorisation of the data elements.

During the course of the research it became apparent that every cost estimate must be based, if possible, on complete and current information concerning the processes and the product being estimated. As discussed in the previous chapter this information comes from many sources, such as drawings, specifications, pictures, etc. A credible cost estimate is formulated by selecting the appropriate cost information from a vast store of knowledge and information resources. The needed information and resources were discussed in the previous chapter and this chapter continues the research.

It is worth mentioning that required cost elements and resources is not all that is required. The cost estimating is still progressing to a point where non-cost estimators or novice cost estimators understand why costs are what they are. For example, cost estimates are needed for decision making, but decision makers often do not understand the basis of these estimates. The cost elements and the links between them are not obvious for novices. Therefore this section defines the essential cost estimation information elements and explains how these elements link together.

For this purpose cost elements are first organised and categorised. This provides the basis for the creation of the information infrastructure. This infrastructure, which is depicted in the form of a web portal, defines the information, recommends sources, and explains why the information is important for cost estimates. The creation of infrastructure required plenty of analysis, although the significant part of this analysis has already been performed in the previous sections. The Web Portal is based on the results of this analysis. This portal provides a comprehensive introduction of costing information.

5.4.1. Categorisation of Cost Elements

The categorisation of cost elements was motivated by two points:

- To provide a logical order for the collected cost elements, and;
- To create the hierarchy for the Web Portal.

Five principles were used to categorise the elicited cost elements.

1. The categorisation is a consensus that brings a structure that fulfils (major) requirements of the automotive companies. For this reason during interviews the author asked how the experts categorise cost information

currently. The responses enabled the creation of the top level structure of the hierarchy.

2. The output is described in a tree format so that the Web Portal can be created. This hierarchical categorisation enables also a proper subdivision of the cost elements into smaller elements. The higher levels of the hierarchy contain generally more aggregated cost elements (e.g. machine cost). The leaves contain atomic cost elements.
3. Cost elements were organised into logical groups. The groups were based on the understanding of the "closeness" between different cost elements. This understanding was gained from the literature and interviews. Few cost elements that are naturally linked together were placed under one cost element (see e.g. building cost below).
4. An effort was made to reduce bundling between cost elements, for example machine price is broken down in to machine purchasing price and machine installation cost. These separations enable to see what is causing costs therefore decreasing the chance of hiding inefficiencies.
5. The elimination of duplications is vital factor for credible cost estimates. The Web Portal contains the logic for this by providing instructions how the information should be categorised. For example, the definition of design, and research and development costs helps to see what costs should be included in this cost element. These bits of logic enable normalisation of information therefore to create consistency between cost estimates.

5.4.2. The Hierarchy of Cost Elements

Figure 5-4 illustrates the generic breakdown of the cost elements described in the cost estimation information infrastructure. At the top there are materials which are processed in a factory. The manufacturing value-adding is done by machines and labour. The factory value-added conforms in general with a part of the common cost estimation process (steps identifying processes, machines and labour). Besides manufacturing people and machines a modern company in the automotive industry has an extensive set of other activities. These activities are included in the general overheads as their costs cannot be clearly associated with particular operations or products.

The figures 5-5 to 5-10 below show the hierarchy of the information. Note that the hierarchy is separated into six different diagrams corresponding to the groups below. The structure of the aggregate cost elements conform to the structure of the

Web Portal. In the figures the cost elements found inside of the aggregate cost element are marked with plus (+) sign. This was done to increase readability of the model. Care was taken to make sure that this does not decrease the accuracy of the infrastructure. Cost elements were grouped into aggregate cost elements if the elements are logically linked together. By doing this the number of nodes almost halved from the original 80.

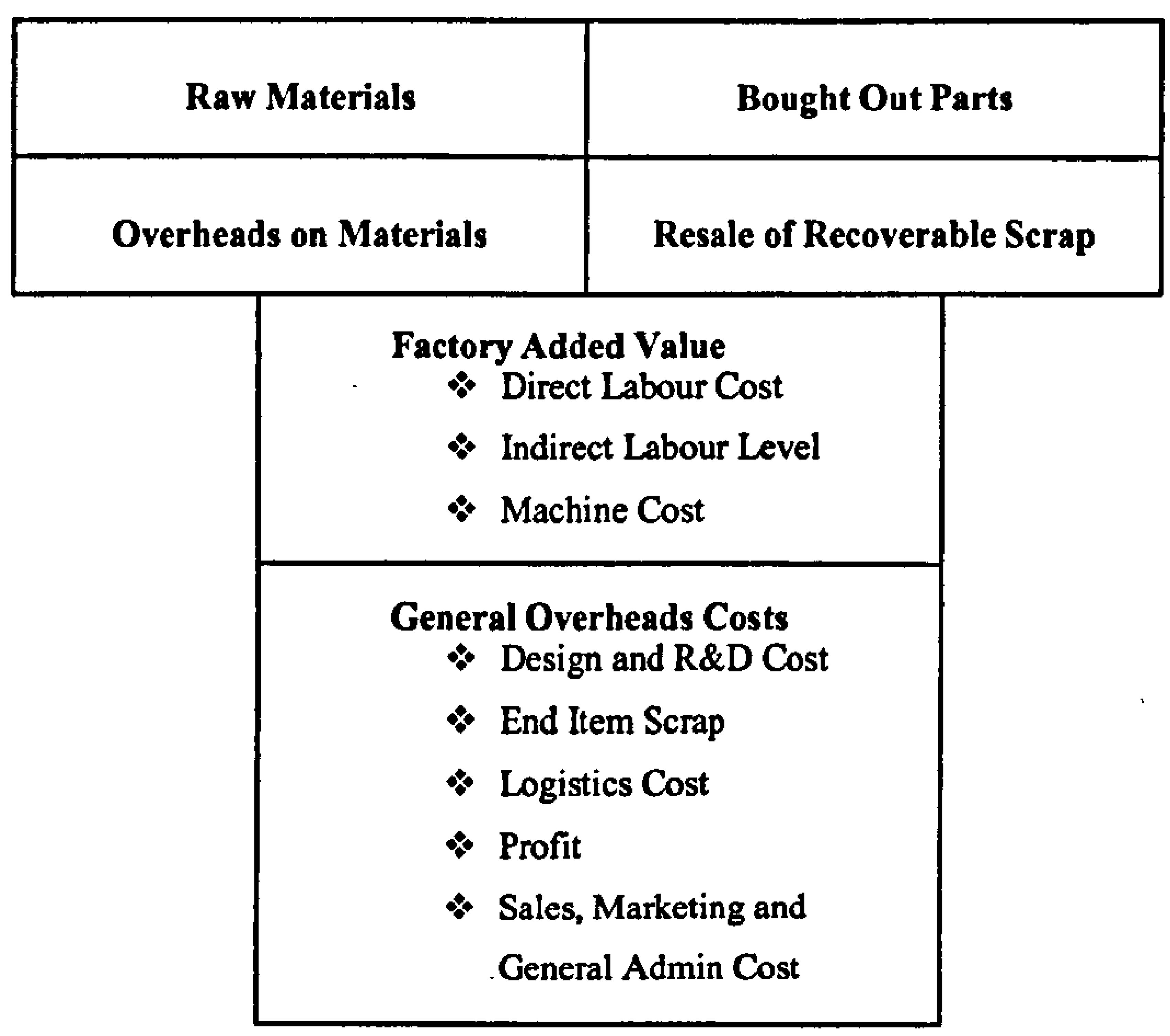


Figure 5-4: Generic Breakdown of the Cost Elements

Total Part Cost

This level contains only three elements (figure 5-5); material, factory value-added and general overheads. Materials are separated because they are input for the manufacturing process. General overheads contain all the cost elements which cannot be identified to the other two categories. The factory value-added consists of both direct and indirect labour, machine and tooling costs.

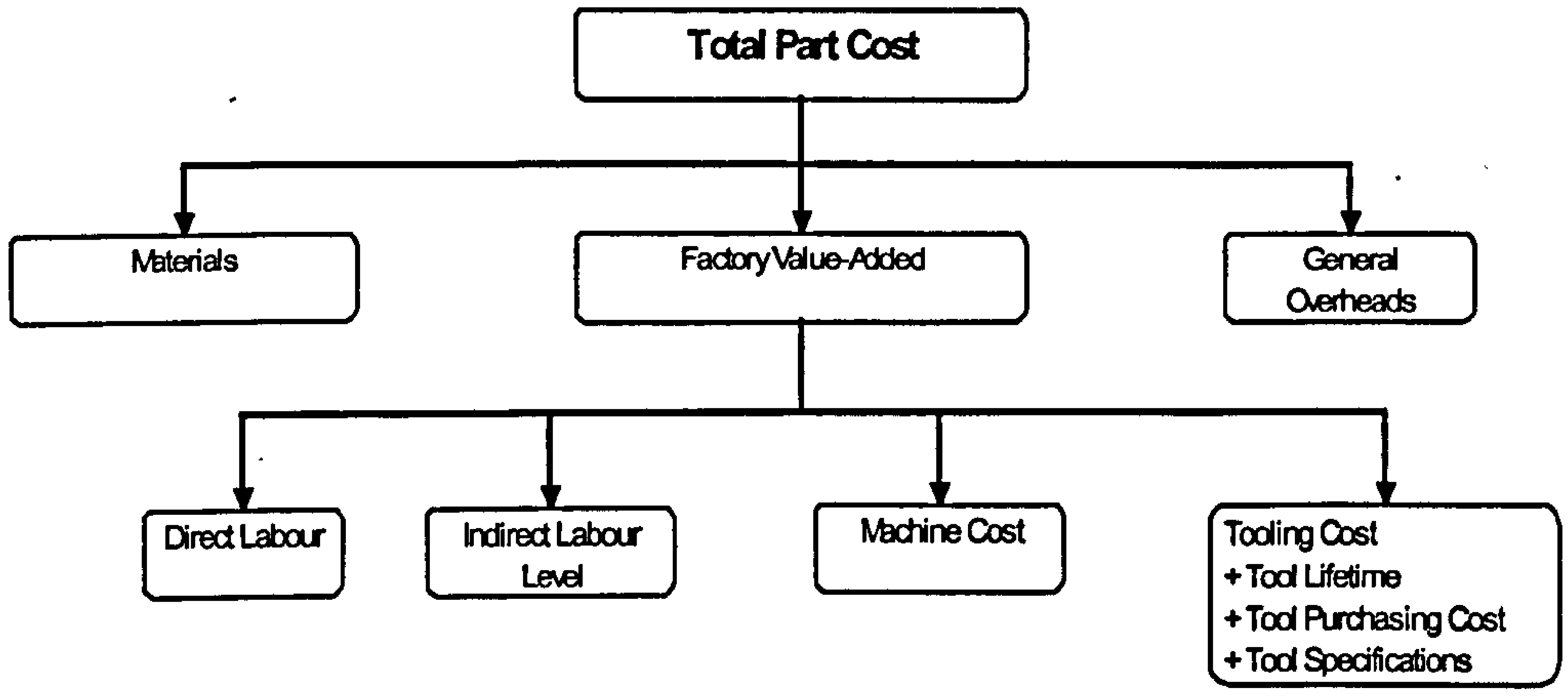


Figure 5-5: Total Part Cost

Indirect labour consists of people who do not directly add value to an item, but assist in some way this value adding in a manufacturing plant. The reason why all people, including maintenance people are included under one heading is that this facilitates the comparison of labour. When all people are grouped under one category the duplications are reduced. The only exception to this is the people handling materials. They are categorised under materials to keep all material costs under same heading.

Tooling costs are separated from the machine costs because tools are changeable parts of a machine, such as cutting tools. These tools are often designed and manufactured to produce a specific part.

<u>Materials</u>

This part of the tree is separated into four sections (figure 5-6). The raw materials part is divided into two sections, one giving general information about raw material and the other explaining raw material rates. For bought out part the structure is the same, expect that bought out part elements are internally separated in the two parts; standard bought out parts and subcontracted items. Third section is the material overhead, which covers costs associated to the administration of purchased raw materials and bought out parts. Lastly, the material usage is covered. This heading also covers the concept of scrap which is the excess usage of material.

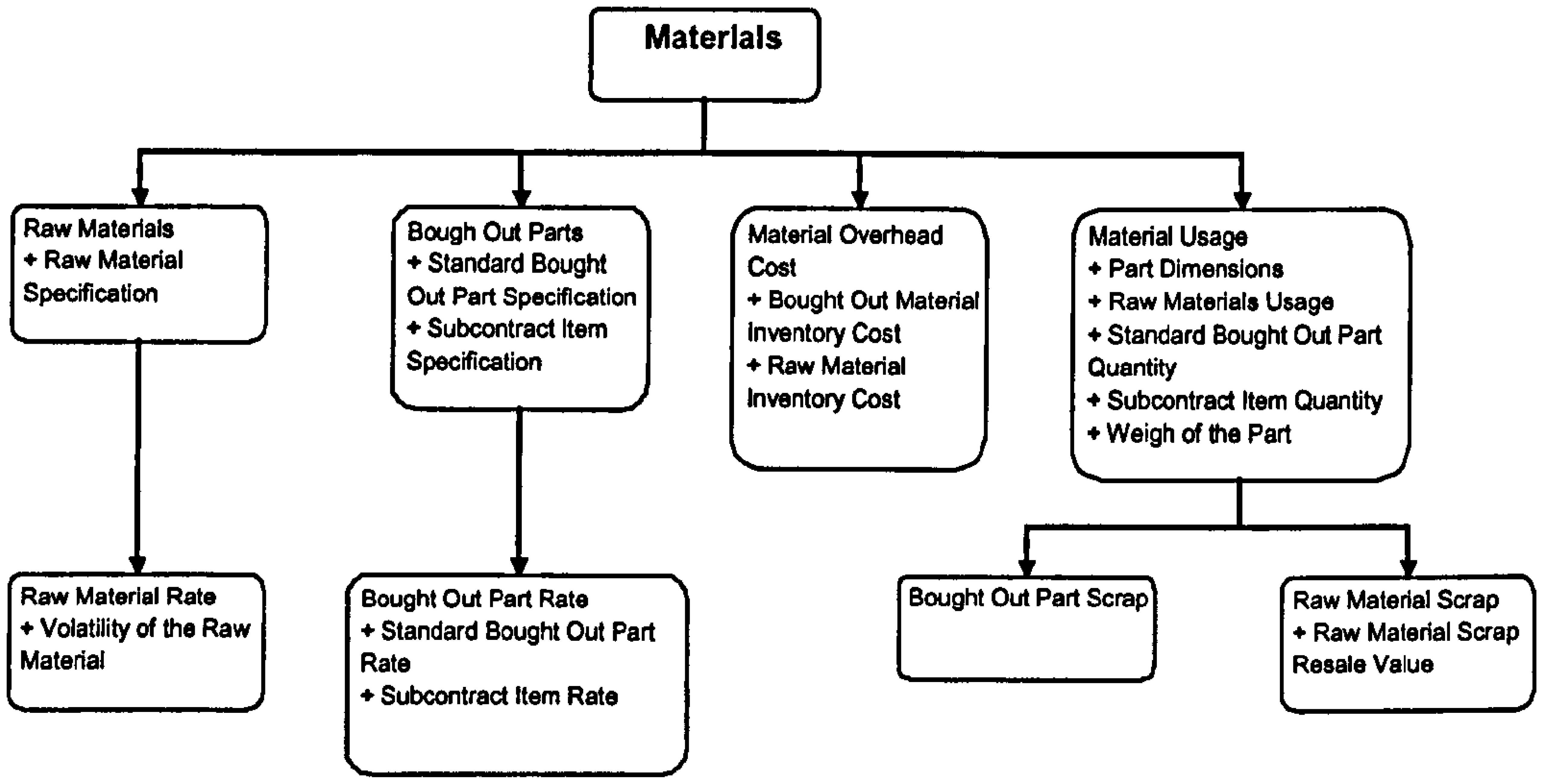


Figure 5-6: Materials

<u>Direct Labour</u>

The direct labour category contains all (human) labour costs which are directly related to a specific item (figure 5-7). The contribution should be clearly identifiable to the product, i.e. direct value-adding. Often direct labourers are machine operators and other manufacturing personnel in the production line. The direct labour contains two major groups; time units used, and a cost of one time unit. Note that number of parts per cycle is an important value; it is used to divide the labour cost. The total operating time is the time for one manufacturing operation. This time is the pure operating time corrected with appropriate allowances, which add realism into the cost estimate. The allowances also enable to analyse how effective the production is. The second group contains direct labour rate, fringe benefits, shift premium and overtime pay. The direct labour rate is the basic cost of employing workers. Their salary is based on their profession (labour category) and skill level. The other three are necessary additional costs for employing workers. The shift premium is affected by the shift pattern used in a company. The shift premium is a compensation for working during non-normal hours. The knowledge of shift pattern is needed for the calculation.

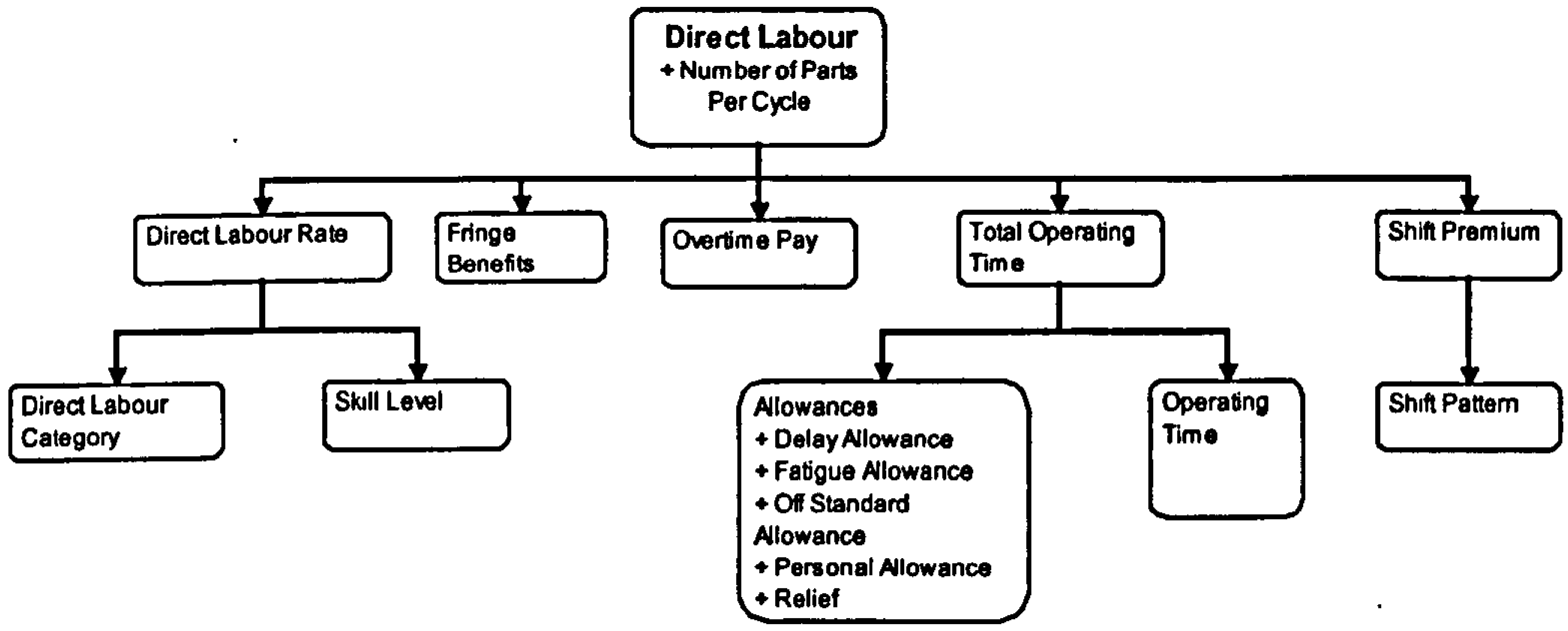


Figure 5-7: Direct Labour

Machine Cost

This group is the most complex one and very important (figure 5-8). The machine costs are a major part of current manufacturing cost, mainly due to high degree of automation in the car industry. The high cost also affects on grouping, i.e. it is detailed. The top structure of this category is somewhat similar to the direct labour category; machine cycle time with number of parts per cycle tells how much machine time should be paid for a part. The machine rate is amount of costs incurred when using machines to produce items, without other interruptions on the production than preventive maintenance (i.e. that is the lowest reasonable cost for well working production). The process scrap includes the adjustment for all the other causes (than preventive maintenance) that might increases machine costs. The separation between machine uptime and process scrap helps to assess the real competitiveness of the production. Note that process scrap is a subset of allowances of direct labour.

Machine rates are divided into five categories. Annual working hours and machine uptime tell much the machine can be used. Machine uptime is the theoretical capacity subtracted by time spent for preventive maintenance. Both of these elements are needed for verification that machines are used efficiently. The three other categories are the actual components which are causing machine costs. Machine depreciation is a diminution in value of a capital costs due wearing and obsolescence of a machine. Its capital cost contains two parts, purchasing price and installation costs. Two other components important for depreciation calculation are machine technical lifetime and possible residual value. Utilities are operational supply items (e.g. electricity) for a machine, therefore directly affecting on machine rate.

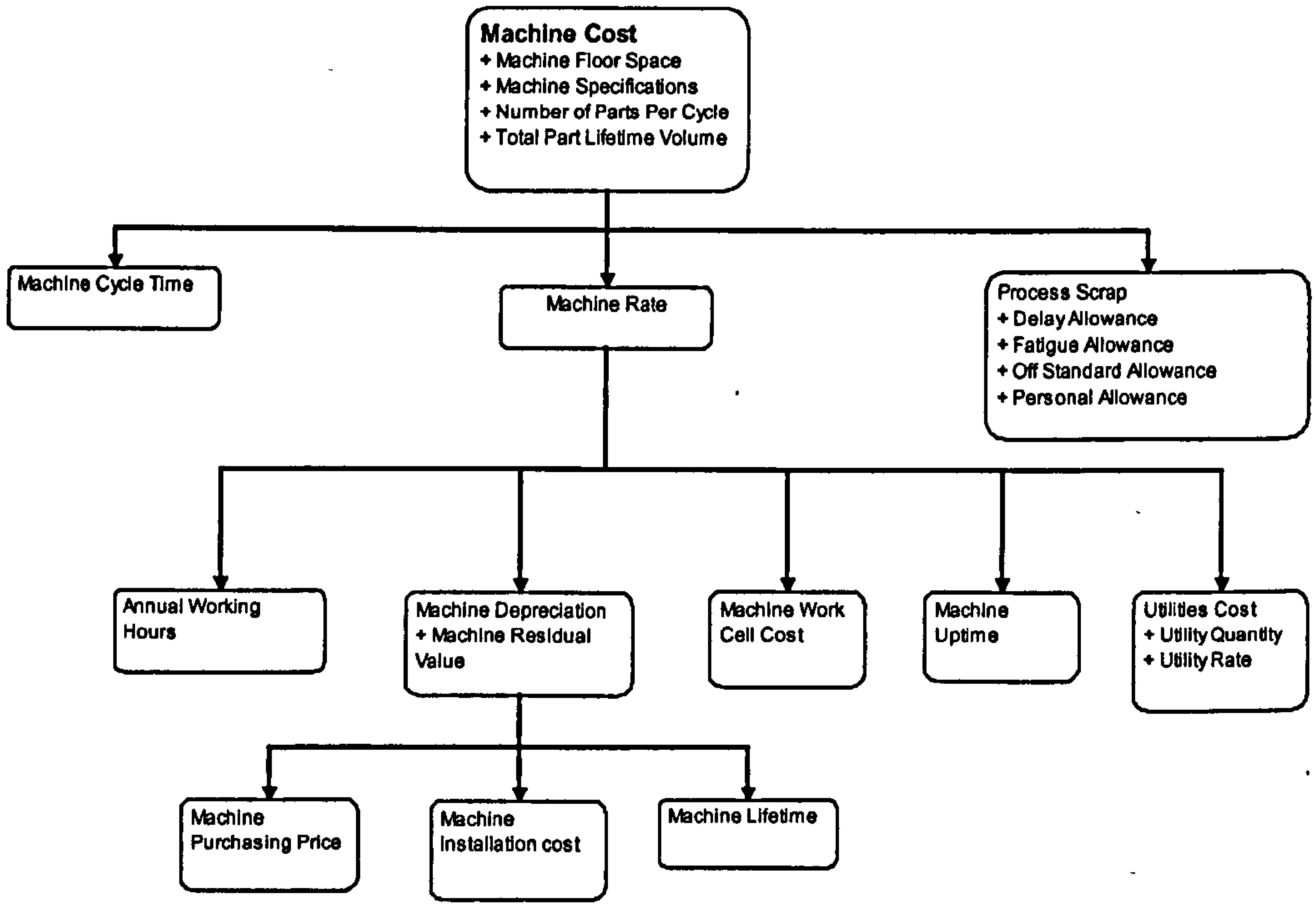


Figure 5-8: Machine Cost

The last member of the machine rate group, machine work shell cost, is a detailed category itself (figure 5-9). It groups together the costs that are required to enable the utilisation of a machine and maintaining production in a work cell but cannot be divided to any particular product but a machine. The category is divided into four parts: (1) building cost which covers the costs incurred to sustain manufacturing capability of a work cell; (2) insurances; (3) machine maintenance, repair and cleaning to ensure the well being of machines, and (4) miscellaneous cost category which includes cost elements that do not fit into other categories. Overall it can be said that although work shop costs are divided into many categories it is not easy to accurately associate a fair portion of them to a particular machine operation.

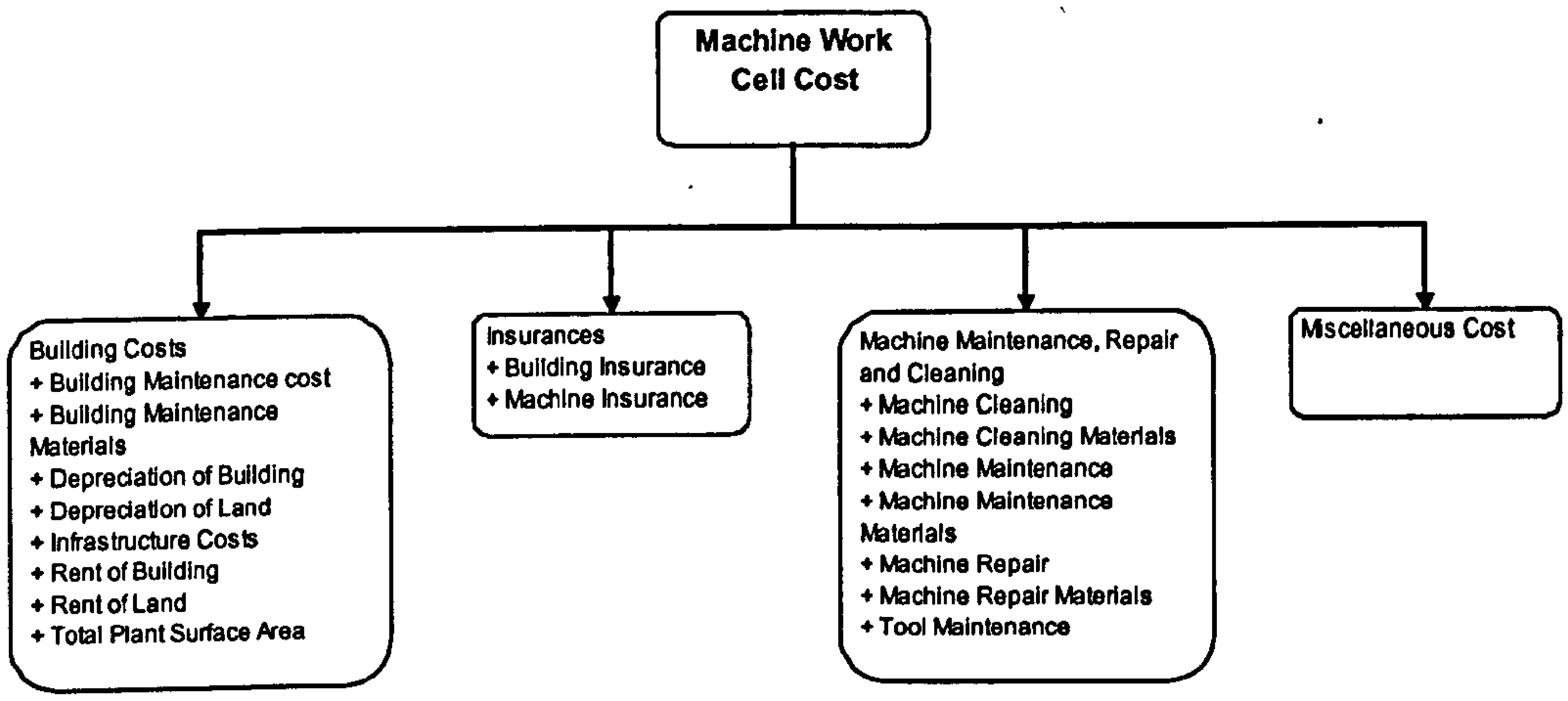


Figure 5-9: Machine Work Cell Cost

General Overheads

General overheads (figure 5-10) are a portion of the cost that cannot be clearly associated with particular operations or products. The cost elements were categorised into five groups. Design, and research and development costs are associated with the development of new products, or improving products and processes. Sales, marketing and general administration costs cover all administrative and other non-manufacturing activities, such as sales that cannot be included into the factory value-added. The third category is end item scrap. It contains costs when finished products somehow are rendered unacceptable, therefore having a direct cost impact. The fourth group, profit, compensates the business risks of supplier that are caused by manufacturing items on the behalf of a buyer. This group is separate because it is assumed that cost estimation is done tightly elsewhere therefore the profit gives a compensation for the supplier. The first four groups are very abstract, but the last one is surprisingly detailed. Cost estimators felt that ex works prices do not give an accurate picture of prices anymore. This is due to heavy outsourcing and geographic spread of suppliers. Logistics cost includes finished product inventory carrying, packaging and transportation costs. Cost estimator may consult logistics people for detailed logistics cost analysis.

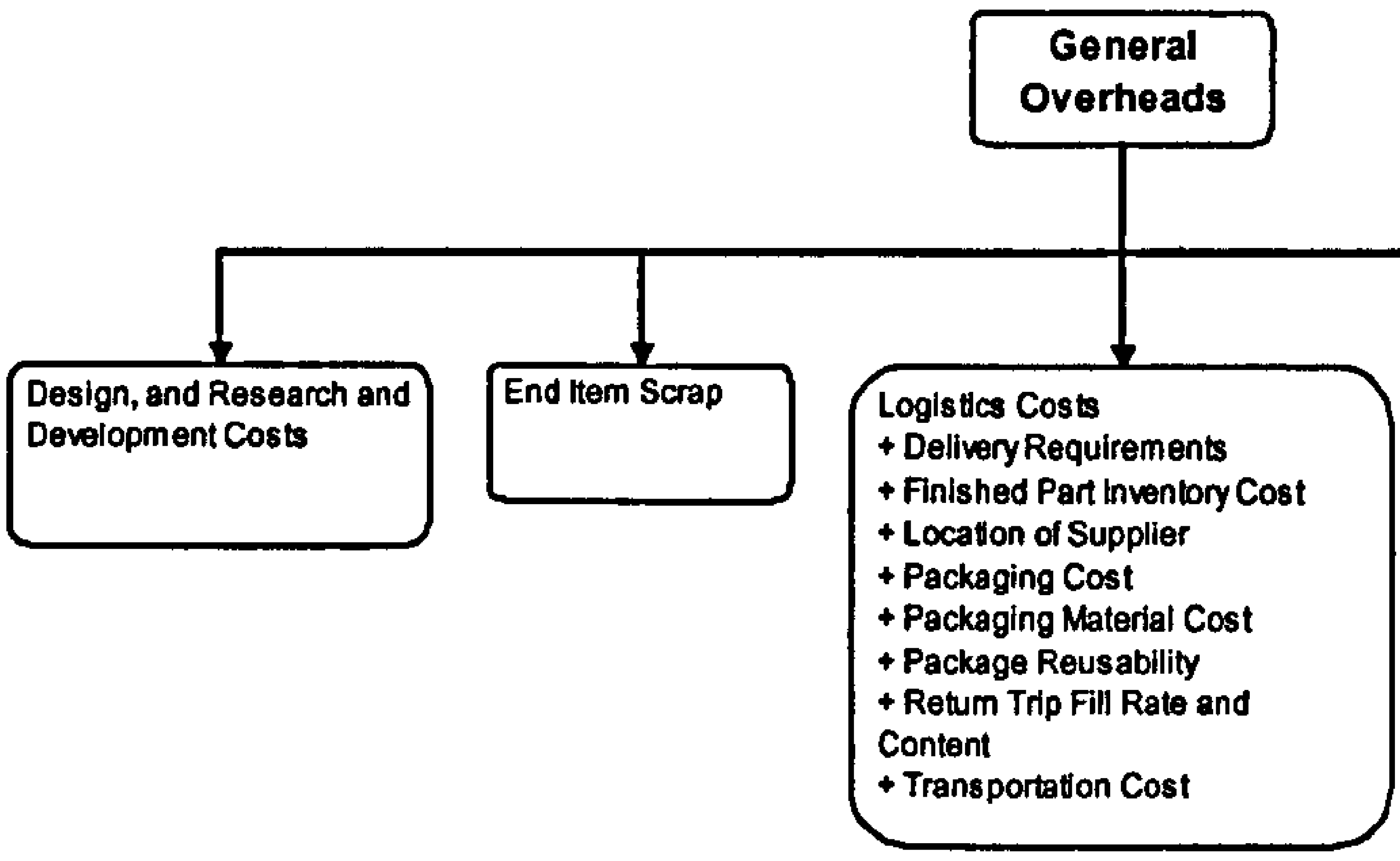


Figure 5-10: General Overheads

5.5. Development of the Data Infrastructure

5.5.1. The Creation of Data Templates

The categorisation of the cost elements provided the basis for the Web Portal. It created the framework and hierarchy for the web pages of this Portal. The last step of the research was to further develop the suitable content for the Portal. The content is called data templates or web pages (figure 5-11).

The major part of the analysis is already described in the previous sections. The relevant cost elements and their resources have already been identified. There were two more points to be covered for each cost element:

- Why they are used
- How to validate and normalise them

As the questions imply both points are highly qualitative. They are tacit knowledge. The elicitation of this knowledge was considered to be important so that the Web Portal can give the full definition of the information.

In figure 5-11 the relevant information about *Fringe Benefits* is presented. A description of what they are, how to normalise them, where to find them and examples are presented. Figure 5-12 presents the organisations where such type of information could be retrieved (with specific suggestions about *fringe benefits* made in figure 5-12).

The material for the information infrastructure was gathered during the interviews. Part D of the questionnaire was developed for this purpose (appendix B). Table 5-2 contains the questions asked to develop the data templates of the information infrastructure.

[Index] [Home] [Up]

Fringe Benefits

Fringe benefits are part of the cost of employing both direct and indirect labour. The fringe benefits are non-salary rewards/costs provided to employees, examples being private pension schemes and luncheon vouchers. The claimed fringe benefit level is important, as this will reveal how well the supplier company treats its workers.

Therefore, the cost estimator should allow *at least the industry average fringe benefits*, as this gives some guarantee that the supplier's employees are well motivated and, most likely, suited to their tasks.

Legislative and company fringes benefits

Fringe benefits can be divided into two categories:

- Legislative, or mandatory fringe benefits; these are normally well defined by e.g. labour laws, government statues, or labour union agreements. These fringes benefits are usually country specific.
- Company specific fringe benefits differ between companies. This is the category where the good corporate citizenship is practised by giving additional benefits.

Finding an appropriate fringe benefit level

To find an appropriate fringe level is not easy. Firstly, in different countries the need for fringe benefit varies, especially company specific fringes. Private medical insurance, for example, might be totally unnecessary. Secondly, even within the same country, different regions have different fringe benefits, e.g. London allowance. Therefore to find an appropriate level of fringe benefit involve various data sources:

- Company's own fringe benefit levels; as automotive companies are global, and they usually operate in various countries. Company's own human resources and financial people can inform about suitable fringe levels for these countries.
- Fringe benefit information may also be available from suppliers. Analysis of information accumulated over many years will reveal a typical type of fringe benefit paid within a specified industry. This intelligence can then be compared to fringe benefit claims of a supplier. These benefit claims can be verified by asking for supporting information from payrolls and human resource policies.
- Statistical information provides generic information about fringe benefits (especially mandatory ones).
- The last option is the purchase of commercial information. This method is easiest as specialised consultancy companies make large surveys within the industry. They can provide detailed information of different fringe benefit options available and their average use within a selected industry. See for example CELRE or IDS.

Examples of Fringe Benefits:

Figure 5-11: Example of the Direct Labour Data Template

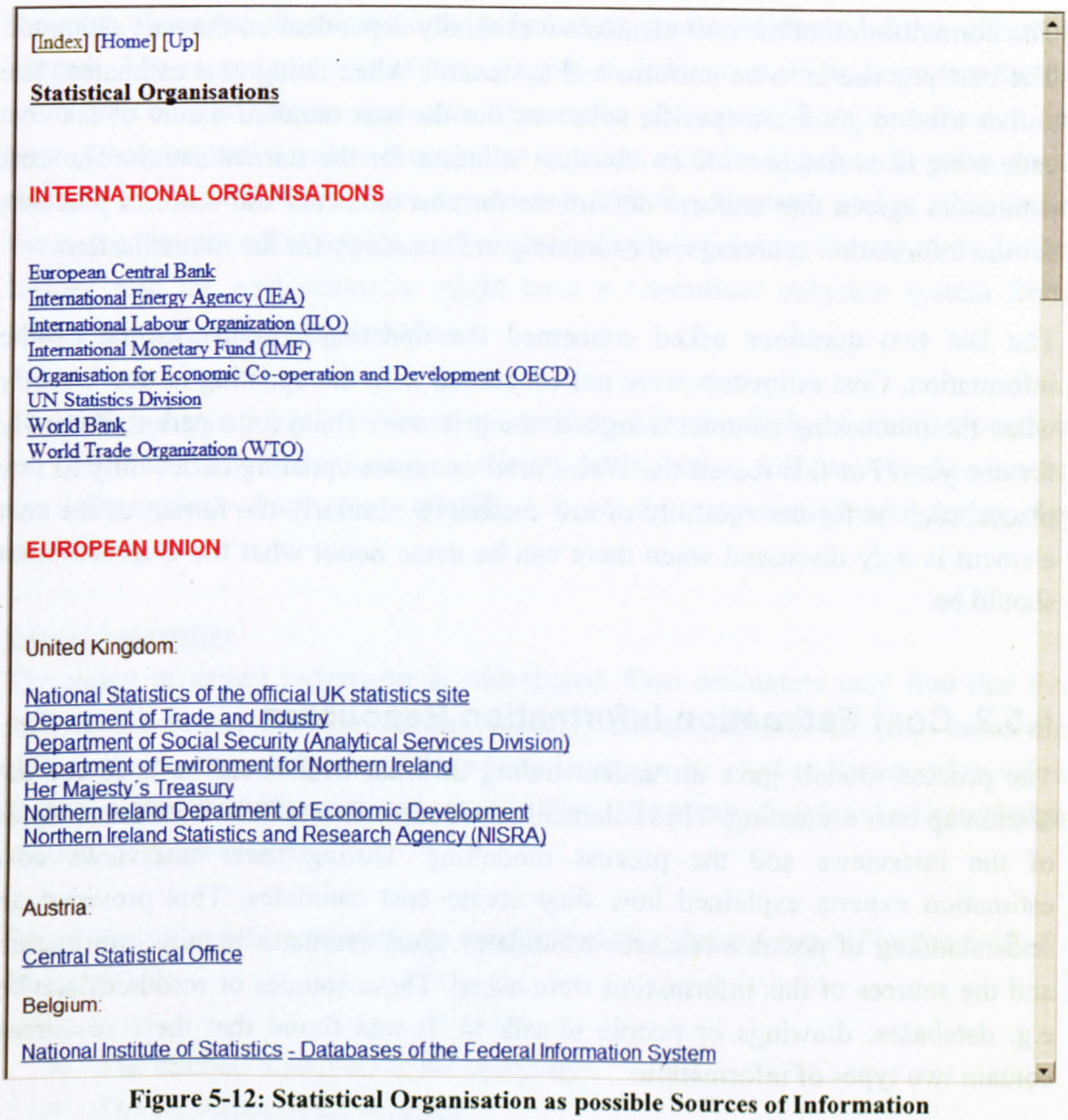
Part D contains eight questions. The first three questions were used in the previous chapter to verify the result gained from previous questions during the interviews. As the questions of part B asked open-ended questions these three questions asked in more structured way the same information. They added certainty that the elicited information was correct.

Table 5-2: Part D of the Questionnaire

Questionnaire, Part D
Where is this information found?
How is it accessed?
When (during the cost estimation process) is this information needed?
Why is this information needed?
How is this information validated?
How is this information normalised?
How often is this information updated?
In what format is the information?

The fourth, fifth and sixth question are the foundation of this section. The fourth question is why the information is needed. This question was asked for each cost element. The answers were argumentations on why the cost elements should be included in the information infrastructure (and therefore used in a cost estimate). Cost estimators provided unvarying answers for most items. They agreed for example that direct labour is an important cost element as labour costs have a direct impact on the total part cost. For some items such as logistics cost there was a wider range of different opinions.

The selection of best methods was based on the qualitative analysis. The cost estimators were challenged. After cost estimators provided their view, different practises found from the literature and from previous interviews were compared to the provided answer. The reason for the difference was asked. It was found that different cost estimators have slightly different emphasis and preferences for the cost elements. The comparison of different practises initiated fruitful discussions with the cost estimators; therefore the fourth question provided plenty of information for the Web Portal.



[Index] [Home] [Up]

Statistical Organisations

INTERNATIONAL ORGANISATIONS

European Central Bank
International Energy Agency (IEA)
International Labour Organization (ILO)
International Monetary Fund (IMF)
Organisation for Economic Co-operation and Development (OECD)
UN Statistics Division
World Bank
World Trade Organization (WTO)

EUROPEAN UNION

United Kingdom:

National Statistics of the official UK statistics site
Department of Trade and Industry
Department of Social Security (Analytical Services Division)
Department of Environment for Northern Ireland
Her Majesty's Treasury
Northern Ireland Department of Economic Development
Northern Ireland Statistics and Research Agency (NISRA)

Austria:

Central Statistical Office

Belgium:

National Institute of Statistics - Databases of the Federal Information System

Figure 5-12: Statistical Organisation as possible Sources of Information

After analysing the initial material the author contacted the cost estimators whose reasoning was unclear or whose argumentation was believed to be the best practise. These further clarifications provided the certainty that the selections made were correct.

The next two questions (fifth and sixth) concentrated on the validation and normalisation of the information. The validation of the cost element is in some cases, such as material rates, difficult but in overall the validation is done by asking written proof, conducting supplier visits, and comparing information found to information from other sources. Benchmarking of the information is common.

The normalisation of the cost elements was totally dependent on the cost estimator. The best practise is to be uniform and systematic when doing cost estimates. The author tried to get more specific solutions but the non standard nature of the cost estimating does not provide an absolute solution for the normalisation. The cost estimators agreed that uniform definitions for cost elements and uniform practises for the information sourcing and estimating are necessary for the normalisation.

The last two questions asked concerned the updating and the format of the information. Cost estimators were not concerned with the updating issues. Usually when the purchasing contract is signed, the prices are fixed for a period, normally for one year. For this reason the Web Portal mentions updating issues only in few places, such as for the volatility of raw materials. Similarly the format of the cost element is only discussed when there can be some doubt what the correct format should be.

5.5.2. Cost Estimation Information Resources

The process models gave an understanding of what data could be used for the bottom up cost estimating. These elements were identified mainly from the analysis of the interviews and the process modelling. During these interviews cost estimation experts explained how they create cost estimates. This provided an understanding of possible resource candidates. Cost estimates require information and the sources of this information were asked. These sources or resources can be e.g. databases, drawings or people to talk to. It was found that these resources contain two types of information:

- Cost information (e.g. direct labour rates)
- Information needed to deduce the cost (e.g. machine specification)

Both types of information are used by cost estimators. By identifying the right source of information, the author could include this information in the data templates and therefore making it easier for the experts how and where to identify it.

During the research it is found that the selection of the correct information source is not trivial. Some of the information sources are "standard" such as technical drawings, but mainly the usage of sources is based on experience. It was established that different cost estimators have different ways to search values for the cost elements; therefore some information might be looked from different sources. The company's way of how it conducts its business is an important factor as to how cost estimators approach information gathering. There is a division on how closely an individual cost estimator interacts with the supplier. In some cases the cost estimator does not have any contact with the suppliers, and in other cases the cost estimator relies totally on the information provided by the suppliers. In the former case the cost estimator might have a centralised database system from where cost estimators choose values.

The author discovered that there is no standard way in which information sources are collected across the automotive industry. This section will describe the sources for information which were identified from the responses made during the interviews.

<u>Expert Judgement</u>

The usage of expert judgement is widespread. Cost estimators may find that the information is not available or the source(s) are not reliable. In these cases the estimators use their judgement. This judgement can be used to "estimate" a value for every cost estimation component identified. Obviously their level of knowledge is crucial for the accuracy.

Below the information sources are categorised into three groups (Figures 5-13, 5-14 and 5-15):

- The internal resources of the company;
- The resources of the supplier;
- The resources found from the external environment.

This classification was based on the view that cost estimators had access to all the information. The resources are arranged in structures and have relationships with each other.

Internal Resources

<u>Technical Information</u>

The basic sources of technical information on the part are *company design catalogues, part specifications, bill of materials, drawings, and physical parts.* The latter three might be taken from suppliers and the physical parts maybe from competitors' cars. Catalogues are used by engineer designers to choose parts for the drawings; therefore the cost estimators can use them as references. Part specifications relate to the performances, materials or the technical details about the part.

Other Departments and People

Engineering design, engineering works, human resources, logistics, manufacturing, purchasing departments can provide important information to cost estimators. Their expertise can give direct opinions about costs or provide expertise to help cost estimation, e.g. logistics people for the evaluation of transportation costs. Some cost estimators noted that especially purchasing have databases which can be used instead of personal communication.

Documents and Policies

Company policies and supplier contracts provide guidelines to follow when creating cost estimates. In most cases these values are given and cost estimators may be allowed the change these values only if the reason is justifiable.

Supplier Resources

The resources classified into this section have one thing in common, the uncertainty of the quality of the information and the accessibility of it.

The supplier always has a better position when cost estimating. The information sources identified from the supplier side can be accessible or not, there are seldom guarantees that the information provided or observed is correct. The supplier can give all the information needed but all information should be validated, e.g. by using external environment resources or benchmarking against other suppliers.

The resources of this category can be divided into two; the forms filled by suppliers and the validation of their claims by asking documented information and making supplier visits.

Detailed Cost Breakdown Forms

These forms are used to ask for information in great detail. The exact content of them is company specific; the level of detail can derive from detailed Quotation Analysis Forms (QAF) or from asking all possible information which has been included in other categories in this chapter. What makes these forms special is the normalisation of information achieved by categorising it. This is done by providing clear instructions of what should be included in each category, e.g., how material handling labour should be included in an estimate. This normalisation is important as each supplier has slightly different views on the classifications between data groups.

The content of detailed cost breakdown forms are not discussed in more detail but the Web Portal deliverable contains similar normalisation logic that can be found from a very detailed cost breakdown form.

<u>Documents and Databases</u>

Possible sources of data can be from: *Salary slips, maintenance contracts, quality inspection reports, maintenance reports, machine purchase contract, payroll, inventory logs, and financial accounts and statements.* These resources are normally used to validate the costs reported by the supplier. The analysis of them takes plenty of time. This applies especially to financial accounts and statements; the information is not detailed in small companies and in larger companies they can be very complex. Although some data exists in software tools available in the organisation, there is a lack of analysis and a lack of published literature in this area.

<u>Supplier Factory Visits</u>

The best supplier information can be acquired by visiting a company and seeing how the work is done, e.g. assessing practices and seeing process flows. The cost estimator must become familiar with the facilities, equipment, and personnel who will perform the work. These visits reveal as much information as the supplier allows.

External Environment Resources

<u>Vendors</u>

Machine vendors, tool vendors and material vendors are good sources of information to verify cost claims. They can also give detailed information of their products.

<u>Labour Information</u>

Local newspaper job advertises, job agencies and labour statistics are sources for finding labour rates and other labour related information. Labour statistics information can be public or bought from consultancy companies. In the latter case all the needed labour information can come from one source. *Labour union agreements and labour laws* also provide information on working conditions.

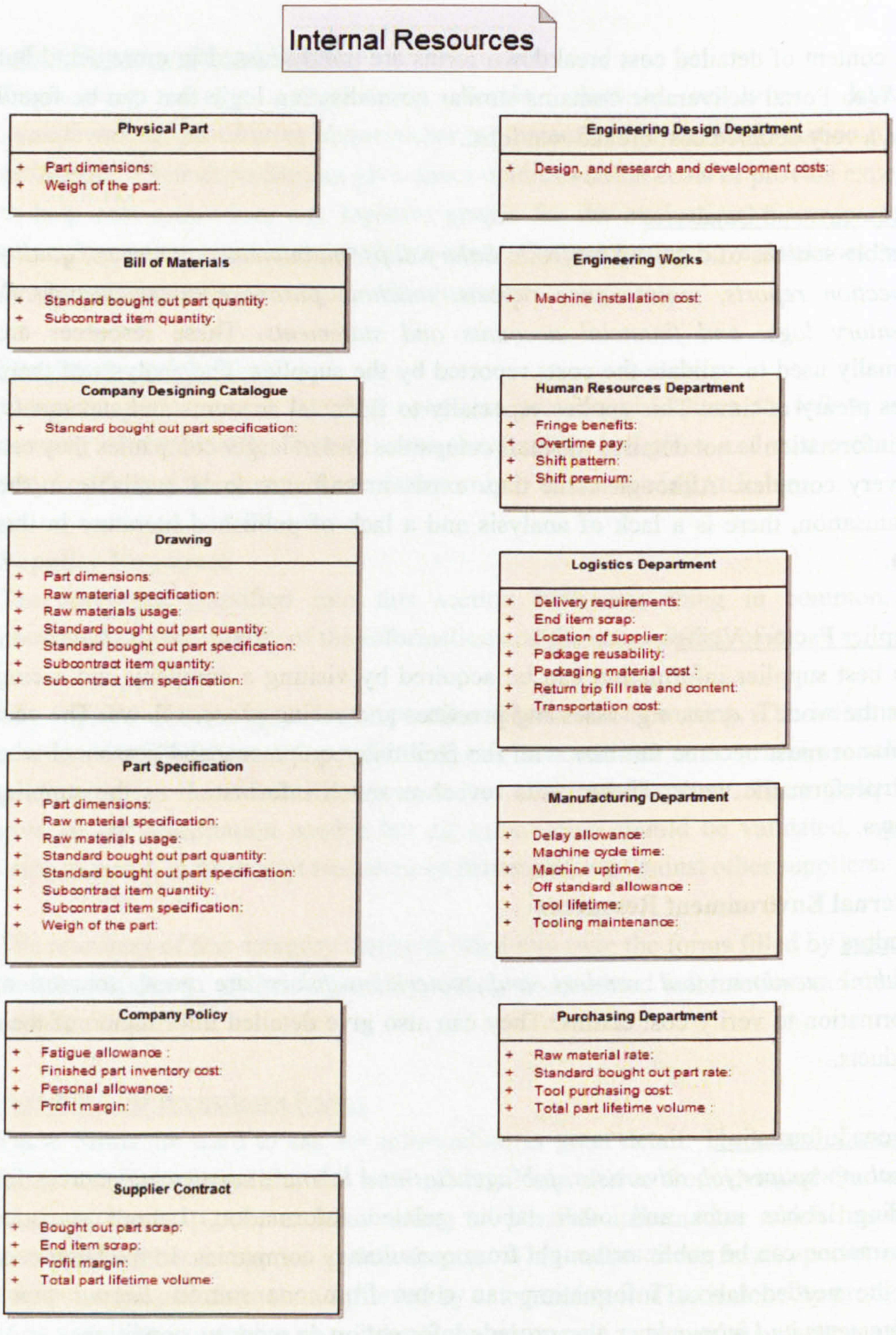


Figure 5-13: Internal Resources and Types of Data

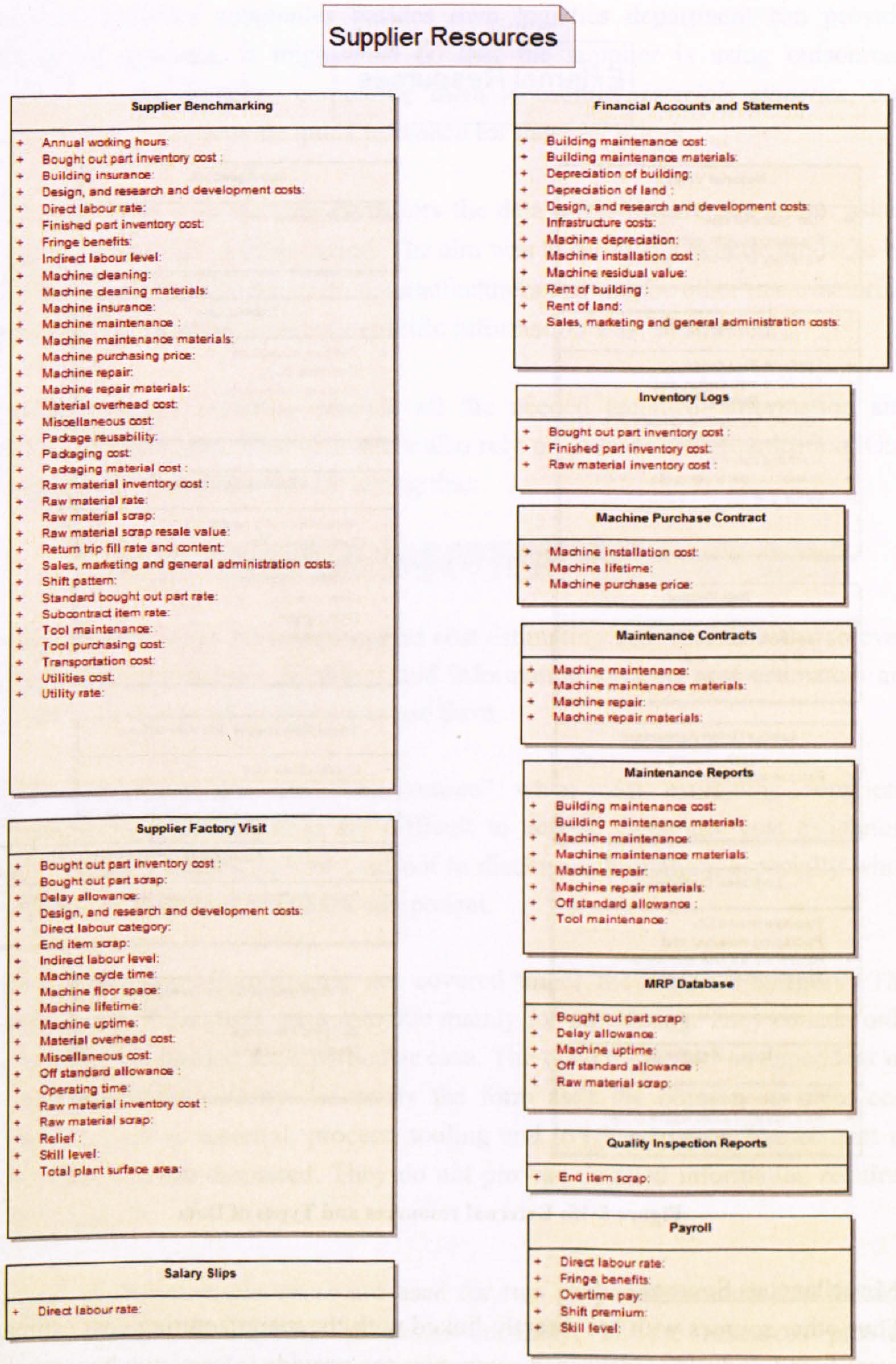


Figure 5-14: Supplier Resources and Types of Data

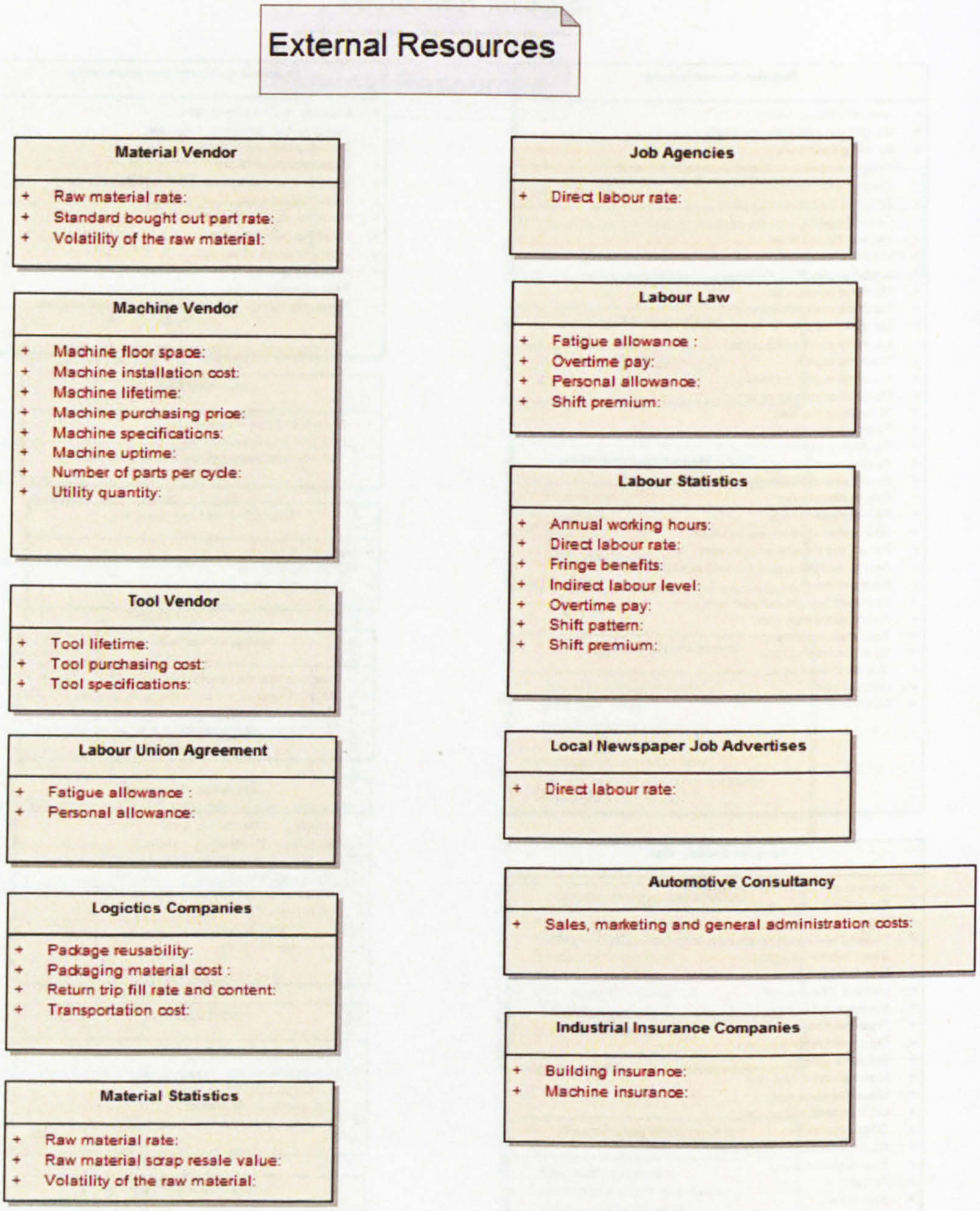


Figure 5-15: External resources and Types of Data

Miscellaneous Sources

Four other sources with are directly linked with the manufacturing cost estimation were found. *Industrial insurance companies* can provide information how much the approximate insurance costs are. *Automotive consultancy* companies can provide information on marketing and other non-manufacturing overhead costs. These costs are difficult to estimate therefore professional help might be helpful. Lastly, specialised *logistics companies* besides own logistics department can provide professional opinions. It might also be that the supplier is using outsourced logistics services therefore comparing them is useful. *Materials statistics*, e.g. Financial Times can provide quick reference for material prices.

When discussing with the cost estimators the data infrastructure, the author asked for generic resources of information. The aim was to develop a generic model to be useful for almost all the automotive manufacturers and maybe other manufacturing organisations. Therefore company specific information was "abstracted".

Internal resources normally provide all the needed technical information and commercial guidelines. Cost estimators also rely on personal communication. One cost estimator crystallised this by saying that:

"When in doubt, ask the expert".

The companies do not normally support cost estimating activities directly, so even if other departments have databases and information systems cost estimators are required to find out and know how to use them.

Supplier resources are the "best source" when cost estimating suppliers. Unfortunately, these resources are difficult to access. Generally cost estimators agreed that the bigger suppliers tend not to disclose information, especially when they have de facto monopoly for a component.

Quotation Analysis Forms were not covered under the supplier category. The reason for this is that they are a resource mainly for purchasing. They contain only key information needed for a particular case. The content of QAF is dependent on the purpose of the activity. Generally the form asks the opinion on main cost categories, such as material, process, tooling and overhead costs. The content of typical QAFs is not discussed. They do not provide detailed information required by this research.

External environment resources are used for two purposes; vendors can provide detailed information of their products. Secondly, all the resources provide information for the validation purposes.

5.6. The Web Portal

This section presents the information infrastructure. This Web Portal is briefly discussed and the results are highlighted in this section.

Introduction

The research aims to identify what are the information requirements in the automotive industry. This would improve the cost estimation activity. As decisions are as good as the information used to create it, providing better information for cost estimating increases understanding how cost estimators construct their estimates. This understanding should lead to sound and justifiable decisions. Novice cost estimators, engineering designers, buyers and other stakeholders can all gain from better understanding of cost estimation elements.

The Web Portal is a structured information package, which defines in depth the cost elements needed in the current automotive cost estimating. The infrastructure gives detailed information about the usage of these elements for cost estimation purposes, and also it gives helpful hints to find information resources. It also provides argumentation why the cost element is important, and how to validate the provided information.

The Web Portal has its academic side which defines the information requirements for the automotive industry. But the Web Portal has been written so that the intended readership can be people who are somehow involved in the cost estimating process. The Portal does not only list information but provides an informative account of each cost element to the necessary detail. Readers may have some degree of cost estimating or cost management knowledge, and aspire to learn more. Non-experts would better understand information used in the cost estimation. However, this site can be also used for reference by more senior cost estimators.

The Users

The web portal was developed to improve the interaction between the disciplines involved in CE. As such the main users will be CE-C and CE-E. Commercial people will be able to understand what is included in an estimate and why, where the information was taken from and what everything means in the estimate. Cost Estimators with many years of experience will be able to use a data infrastructure which is clearly defined across their organisation. Novices in CE will also benefit greatly from the use of the tool as it explains most of the fundamentals with regards to what information you need to develop the estimate.

The Structure

The Web Portal presents findings of the research in a visible and organised manner. The Portal is a collection of web pages created using Microsoft FrontPage 2002. The deliverable is accessible via any modern web browser because HTML (Hypertext Markup Language) is used to describe the content.

The content of the data templates (that is web pages) offers an extensive coverage of cost elements based on all analysis made for the thesis. The information is categorised and organised into logical groups as explained above. The Web Portal is hierarchical by nature; generic concepts are subdivided into more atomic cost elements. This enables to see how different elements are related together. The cost elements are cross-referenced by using HTML hyperlinks between the pages. This allows the user rapidly discover the linkages between elements and to browse through the web site. The Web Portal also provides an index which helps to see all the cost elements and other supportive pages on one index page.

The content of the Web Portal is based on the identified best practises for each individual cost element. Described best practises are generic enough so that the content is beneficial for different cost estimators and companies.

Data Templates

Data templates inside of the infrastructure define each cost element used in the automotive industry. They explain in detail why cost elements are relevant and identify possible sources where cost estimators can find values for them. Each data template answers on at least the following questions;

- What is the cost element
- Why it is used
- What are information sources for it
- How to validate the information

Some cost elements contain more information when that is relevant for the correct understanding. Examples can be the difficulty of material rate estimation, or the expertise needed for measuring operating times correctly.

Data templates contain the information specified above but are not restricted to artificial structures. Good examples of this are possible notes sections. These sections illustrate some additional information that might be useful to better understand the characteristics of the information.

The information resources were discussed in more detail in the previous chapter but the Web Portal is much wordier on the description of the resources. Because the importance of information sources were emphasised during the research, the Web Portal goes into more detail on this issue. Besides listing resources it also gives in some cases web links to information sources. These sources are for example material, machine vendors or statistical agencies. These links address the issue when more detailed information sources are not available, maybe because of the supplier is reluctant to release information, because time pressure prevents collection of more detailed information, or 3rd party information is needed for the validation. But when using these sources it is important to read mentioned limitations for the corresponding cost element.

5.7. The Infrastructure and the Common Process

The common process model and the information infrastructure are not separate deliverables. This section briefly discusses the integration of the infrastructure and the common process model.

The common process model was created not only for investigating resources and information but also to support the usage of the information infrastructure. The common process model provides a list of cost elements to use during the each step of the cost estimation process. The lists support the cost estimation task by providing understanding what cost elements should be used during each step. The information infrastructure contains the corresponding cost elements of the common process model; therefore the cost estimator may easily find the required cost elements from the infrastructure during the cost estimating activity. The data templates of the infrastructure can provide further guidance on cost estimation information, which may be consulted when necessary.

Therefore there is a link between the common process model and the infrastructure. When using the model it is possible to use the infrastructure for further clarification and vice versa.

5.8. Validation

The analysis of the cost elements was qualitative therefore the validation of the web portal was necessary. The author chose the best practises based on the analysis done during the research and further clarified problem points when necessary. The completed Web Portal was examined by two senior cost estimators from two different automotive companies, one with eleven years of experience in commercial issues and the other with thirteen years of experience in engineering issues. One of them was originally interviewed and the other one provided a fresh view on the project. Both suggested a couple of minor corrections, which were implemented after checking their suitability with the overall model. The changes related to the correct terminology and wording of some of the explanation provided in the web portal.

Both experts where asked if the Data Infrastructure improves the interaction between CE-E and CE-C. They both agreed that the study defines the terminology used in CE both for commercial and engineering point of view; therefore it improves the cost estimator's understanding of each other domain and improved communication. The communication improvement in terms improves understanding and interaction between the groups and as a result improves CE internal practice.

5.9. Chapter Summary

<u>The Process Models</u>

Section 5.3 analyses the results of the common cost estimation model. When analysing benchmarking and detailed cost estimating conducted in the companies, it was found that both are using similar cost elements. Based on this finding a single common cost estimation process model for the automotive industry was developed. The model is based partially on the work of the AS IS, chapter 4 and on the process maps presented in Appendix C.

The model described the workflow used when estimating costs, both how to create a detailed cost estimate and how to analyse benchmarking information. The model shows how well structured cost estimates should be done and what information to use during each step. It tries to be as simplify as possible without losing necessary detail. It logically follows through cost estimation process and concentrates on the important aspects of cost estimation and tries to achieve the commonality across the industry.

The Data Infrastructure

During this chapter the cost estimation information infrastructure, was built. The development of it was based on the cost elements and resources identified.

Further analysis was conducted for the creation of the Web Portal, which is the physical presentation of the information infrastructure. First the cost elements were categorised. The categorisation was a consensus that fulfilled major requirements of the automotive companies. It organised cost elements into logical groups and reduced the likelihood of bundling between cost elements. The categorisation produced diagrams containing all the cost elements. These diagrams form a tree hierarchy, and the cost elements were categorised into this tree hierarchy. This tree form was chosen because then the hierarchy was directly suitable for the information infrastructure. This hierarchy provided the basis for the creation of the Web Portal which presents the findings of the research.

The research elicited several resources used by cost estimators in the automotive industry. The number of specific sources was observed to be great. The large amount of different sources suggests that there is no standard way how information sources should be used. The cost estimators agreed on this during the interviews. This has led sometimes to situations where different cost estimators making similar estimates have different results because of the choice of the resource. This seemed to relate to the fact that for many cost elements there is many different resources available. Therefore without corporate guidelines it is difficult to harmonise what sources individual cost estimators are using.

The sources were classified under three major headings; internal resources, supplier resources and external environment resources. The internal resources provide mostly technical information of a component and expertise for particular situations. Supplier resources are the main source of information. Cost estimators can ask variety of information from the supplier but the validation of the provided information is an issue. Also there are no guarantees whether the supplier grants an access for this validation. Therefore it is normal practice to source information from the external environment for this validation. The second benefit is the speed of getting information for some cost elements.

It was found that cost estimators use resources for getting two different types of information; cost information and information needed to deduce the cost. Also it was observed that there is a difference between the information available from the resources and the actual information used it is only portion of data available was used, therefore the used cost elements are mere subset of all the information available. The author selected 80 cost elements from these resources. A cost element was selected if cost estimators considered it to be both relevant and actually usable for the creation of a cost estimate.

Web Portal

Section 5.5.3 addressed the creation of the data templates (web pages) for the Web Portal. These templates define each cost element used in the automotive industry. The content of data templates is based on the identified best practices for each individual cost element. The templates explain in detail why cost elements are relevant for cost estimation and identify possible sources where cost estimators can find values for them. Each created data template answers at least the following questions; what is the cost element, why it is used, what information sources are available for it, and how to validate the information.

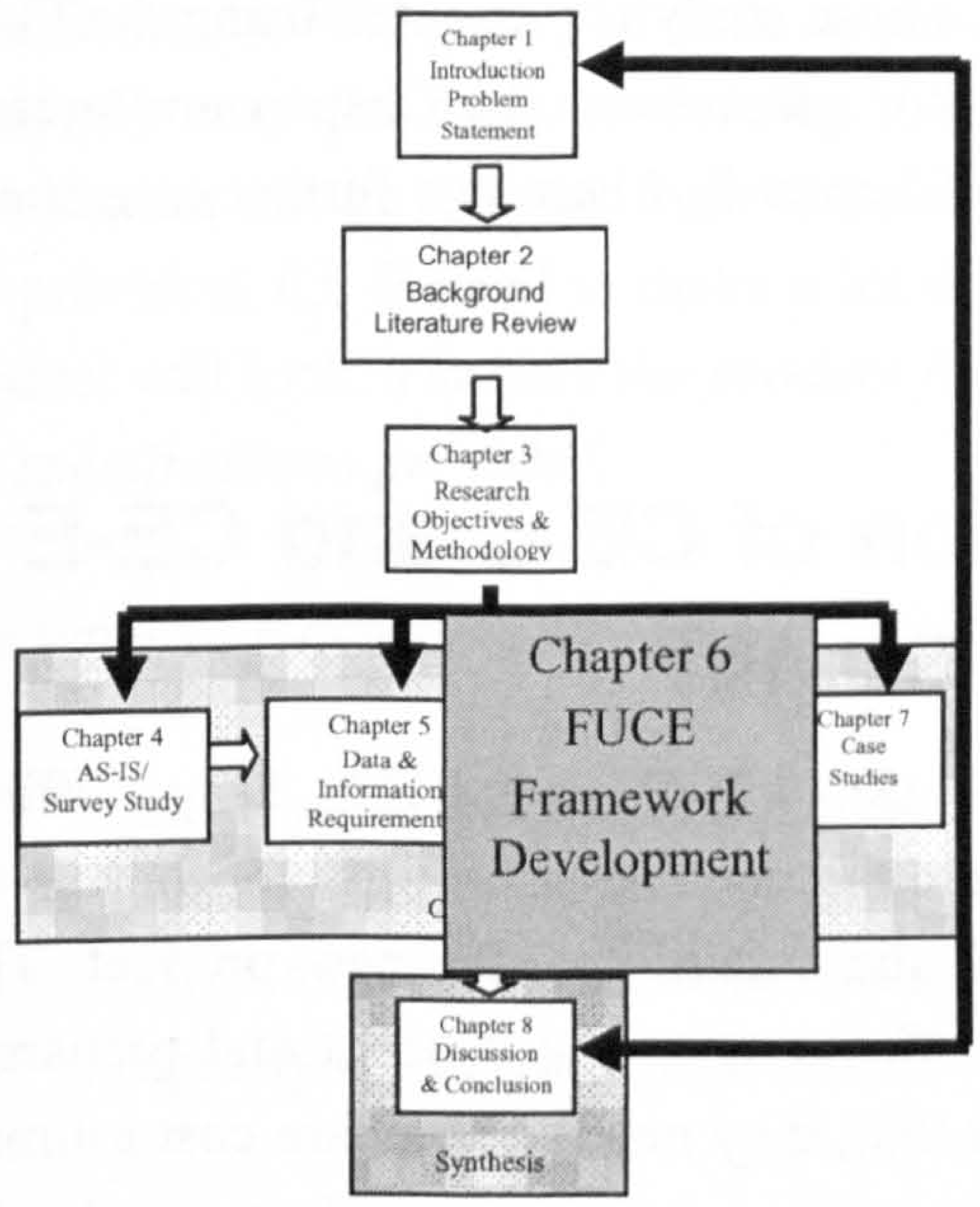
The combination of the hierarchy and the data templates together created the Web Portal. It is a structured information package, which defines in depth the cost elements needed in a visible and organised manner. The Portal has been written so that the intended readership can be people who are somehow involved in the cost estimating process.

The author believes by providing the information infrastructure for cost estimating, a certain level of reliability and consistency can be induced to the cost estimating process thus improving the interaction between the commercial and engineering disciplines within cost estimating as identified by chapter 4 and the introduction of chapter 5.

In the next chapter, the author describes the second important contribution that was identified from chapter 4, the function-based cost estimating approach. The structured framework provides a basis to improve interaction between CE-C and CE-E and the CE internal practice.

THIS PAGE IS INTENTIONALLY LEFT BLANK

6. Function-Based Cost Estimating



In the previous Chapter, the development of the data infrastructure for estimating manufacturing cost was presented. The cost estimating process that is followed within the majority of the automotive companies was established. This allowed the identification of the cost elements that are needed to create a cost estimate. A list of eighty elements and the resources from where they can be retrieved was selected from the cost estimators themselves that were found to be relevant and usable in the creation of an estimate. It was found that cost estimators needed resources for retrieving two types of information: costing rates and information related to the resources "consumed" in order to manufacture the product (machine specifications, material melting temperatures, etc.). Finally, the data infrastructure was developed and validated by the estimators and presented in the form of a web portal (data templates).

The above work was conducted as part of the findings the researcher identified in chapter 4 (AS-IS). Those findings identified two major needs:

- The need for a data infrastructure for manufacturing cost estimating and;
- A framework for improving cost communication across commercial and engineering disciplines within CE.

Chapter 5 addressed the first requirement, therefore the objective of this chapter is:

Chapter Aim:
To develop a structured cost estimating framework to improve interaction between commercial and engineering disciplines within CE at the conceptual design stage.

In Section 6.1 the author describes the reasoning behind his decision to use product function and cost estimating techniques to achieve his aim and describes the Function-based Cost Estimating (FUCE) framework. In section 6.2 the detailed methodology is presented. In section 6.3 a case study is presented using the FUCE framework. Finally in section 6.4 the author summarises the Chapter and presents the key observations before moving onto Chapter 7, where two further case studies are implemented.

6.1. Improving Interaction of CE-C and CE-E at the Conceptual Design Stage

As discovered during chapter 4 (AS IS), CE-C and CE-E have different responsibilities. At conceptual design stage the main responsibility for the CE-C is to prepare a project proposal and check the feasibility of a new product. Their responsibility is to put together the *specifications* of the product and prepare its likely target costs for manufacturing. For that, they need to compare cost estimates with the historical data available to them from previous products made. The information available to CE-C at this stage is quite abstract as it only includes the requirements of the product. The information included in the 'cost information packs' (see section 4.2.3) has the form of a list of requirements the product needs to perform and in some cases a conceptual drawing. This is an evolving document which if the project progresses, will include more information until all the required detailed cost estimates are included prior to the manufacturing stage.

During the conceptual design stage the CE-C will have to make some decisions together with the product design team about the *specifications* of the product and try to create a cost estimate. For example, in the case study examined in the next section which uses the muffler system, the experts will have to specify in what type of car the exhaust system will have to be installed. In most of the cases, this group of people have the expertise to identify what are the specifications of the product but cannot relate how these specifications will affect the product itself and its functions. They lack the engineering knowledge of the CE-E to understand the full effect it will have on the design and cost. The financial techniques used by CE-C are not always adequate due to their relative simplicity (section 4.2.6) and the target costs produced do not have sufficient back up information that elaborates its values. At this stage, the CE-C will request from the CE-E to provide an estimate.

This is where the problem lies, between the interactions of the two groups. As was observed in chapter 4, the required input for CE-E to prepare a detailed estimate has to have the form of a detailed design, a physical product or the product specifications. When the CE-E have either a physical part or a detail design, it is relatively easy for them to develop a detailed estimate as most of the required information can be derived from those two mediums. But when the Specifications are provided, CE-E need to make a lot of assumptions with regards to the way the product will look. *The way the product functions will be fulfilled will be affected by the specifications provided.*

The types of requests CE-C will ask the CE-E are for example:

- "How much will the exhaust system cost if we increase the engine capacity of the vehicle?" or;
- "How much will it cost to add all-wheel drive to the vehicle? With a small capacity engine or a large one"

At the conceptual design stage this is the type of questions a CE-E will receive, *un-quantified request*. The CE-C are not looking for detailed estimates but for an approximate cost in order to be able to make decisions. CE-E, using the bottom-up process will try to acquire more information regarding the product in question and try to use their expert judgement (see section 2.2.1) in order to provide the answer. There are a series of problems associated with this approach:

- CE-E make assumptions that are not documented;
- Results are not repeatable;
- Results cannot be explained easily to another cost estimator as they are based on the assumptions of an individual and are not necessarily the most complete.
- The whole process is not systematic.
- In many cases CE-E make assumptions that are not agreed with engineers, leading to errors in the cost estimate.

While developing a cost estimate CE-C think in terms of the overall car specifications. They often lack knowledge to link the specifications to functions and design. In case of estimating cost for a product they fail to appreciate the impact specifications will make to a design and its functions. If not communicated clearly and in a systematic fashion, explanation from CE-E is often treated with caution as 'over estimation'. On the other hand CE-E develop estimates in a detailed manner using design and manufacturing knowledge. They often fail to link design with its overall function in the car. CE-E often criticise CE-C estimates due to the lack of underestimating or appreciation of product and cost issues. FUCE provides a framework to 'link' the specification-based thinking of CE-C with the product functions and then with detailed cost estimate based on the design. The framework will allow CE-E to answer specific questions asked by CE-C. This improved interaction certainly enhances the internal cost estimating practice with the automotive industry.

Design of Research

The methodology was developed with the help of a large automotive organisation. Participants included a person from the product development department (in this case representing the CE-C) with 12 years of experience in the automotive sector, a CE-E with more than 10 years experience in Cost Estimating, a product engineer associated with the commodity under investigation for more than 6 years, and a person from Tear-Down being in the company for 8 years. In total four people were involved. Tear Down is a facility that exists in most of the large automotive manufacturers, this group acquires cars and dismantles them in to its components; this allows engineers within the organisation to investigate how the competitors manufacture similar products and perform benchmark exercises to identify opportunities for design and cost improvements.

The methodology was validated with a case study which is presented in section 6.3. The case study lasted for a period of six months. The author compiled the steps of the methodology as he thought appropriate. Then with the assistance of the experts involved in the team, the framework was refined until it was considered acceptable by the experts that participated in the study.

6.1.1. An Overview of the FUCE Framework

The objective of FUCE is to 'translate the *un-quantified* terminology and the requests associated with the product specifications used by CE-C into a medium that CE-E can process using their resources, and create estimates that are based on a standardised approach. The model can be broken down into three basic stages:

Stage 1: Functional Decomposition

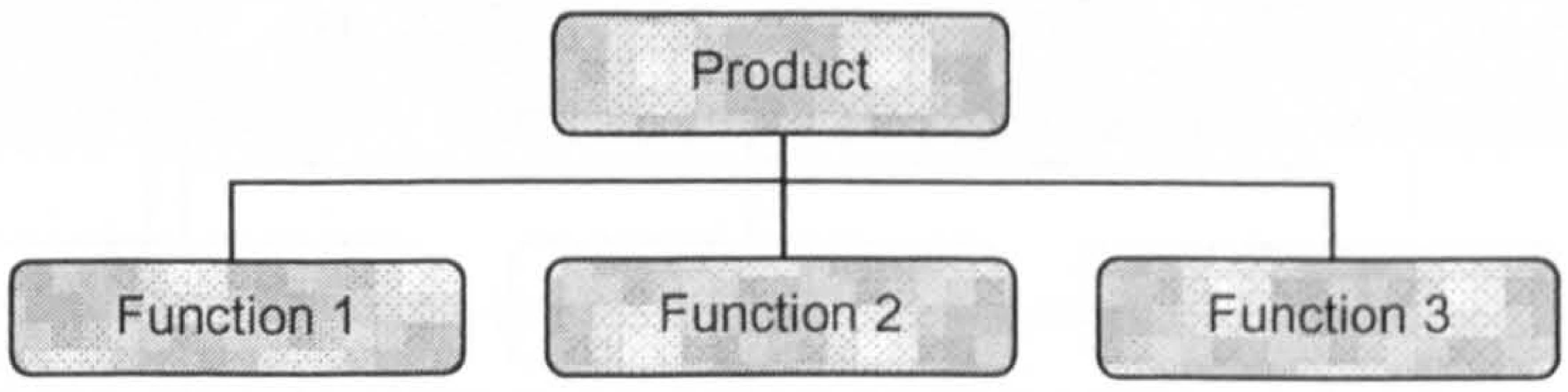


Figure 6-1: Stage 1 Functional Decomposition

In order to analyse how the product is affected by the specifications, the functions of the product need to be analysed. The product is broken down in the basic functions it needs to fulfil, for that purpose functional decomposition techniques are used as reviewed in the literature (section 2.3.2.).

Stage 2: FUCE

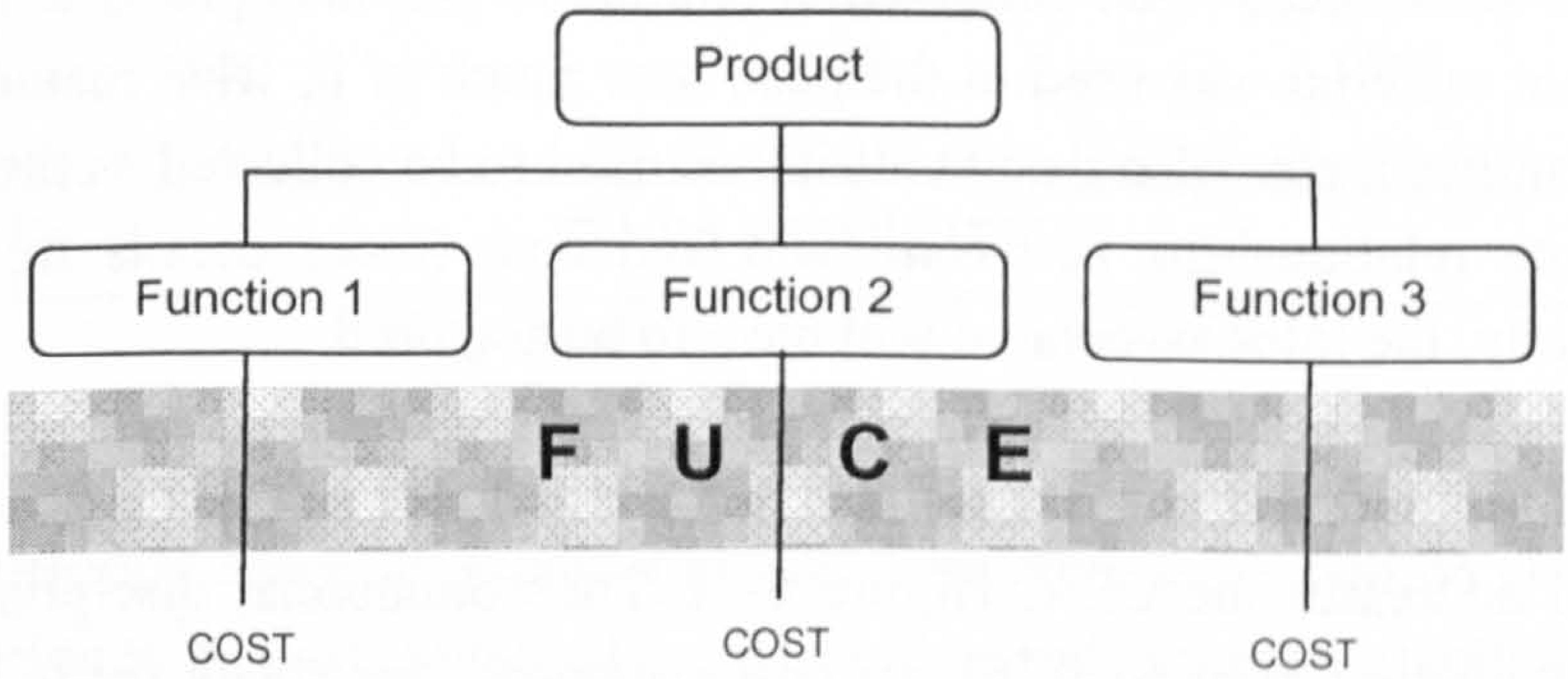


Figure 6-2: Stage 2 FUCE

The next step is to try and identify what physical parameters affect the product and try and associate a cost to them. The objective is to try and answer the questions "How much will it cost me to add this function on my product?" and "How will the specifications affect the cost?" It is important to note that this is the type of questions CE-E are required to answer at conceptual design stage. As we are going to see in section 6.3, the resulting cost estimate can have a range of values depending on the way certain functionalities are performed.

Stage 3: Data Acquisition

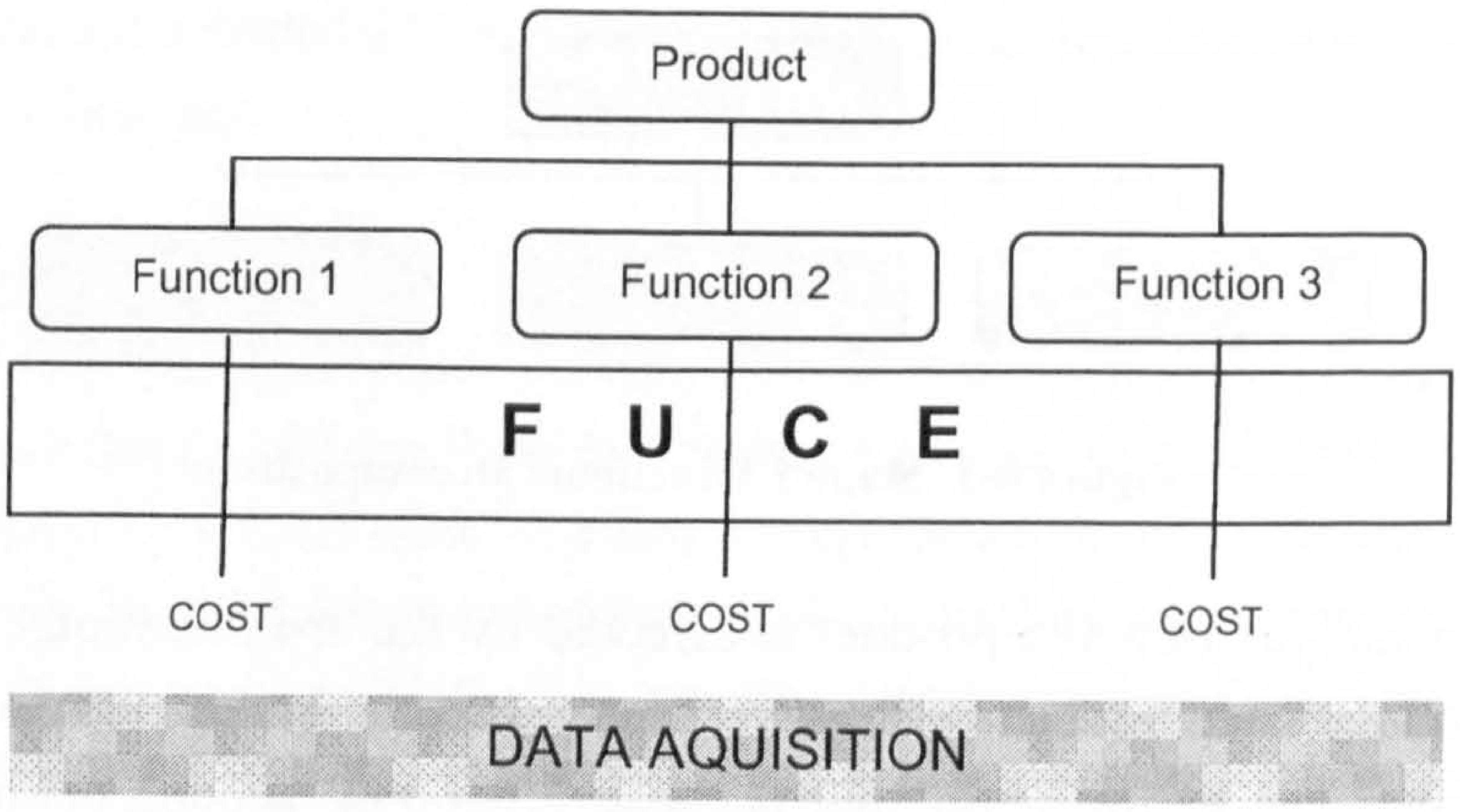


Figure 6-3: Stage 3 Data Acquisition

The last stage relates to the needs of the data requirements to create a successful cost estimate. Data needs to be collected in relation to previous products made, for example, what material was used in the past, how much of it, what manufacturing process was utilised, etc. Also design attributes need to be collected as they will be used to create relationships between them and cost (more details in the next section). Finally, the rates associated will have to be acquired.

It is important to note that this model satisfies both CE-E and CE-C. The first part of the model addresses the CE-C (figure 6-5). The commercial discipline for the majority of their time tries to fulfil customer requirements. They try to fulfil the *wants* and the *needs* of the customer. The objective of the framework is for the CE-C to be able to configure the specifications that affect the product functions more and get as a direct result of that a cost estimate summary of the product costs. These costs have been assigned to functions using relationships created with product experts and cost estimators. In this way, the commercial estimator will be able to retrieve meaningful and rational estimates, at conceptual design stage, based on the functions their system will need to fulfil. That will help them especially at proposal preparation and strategy costing.

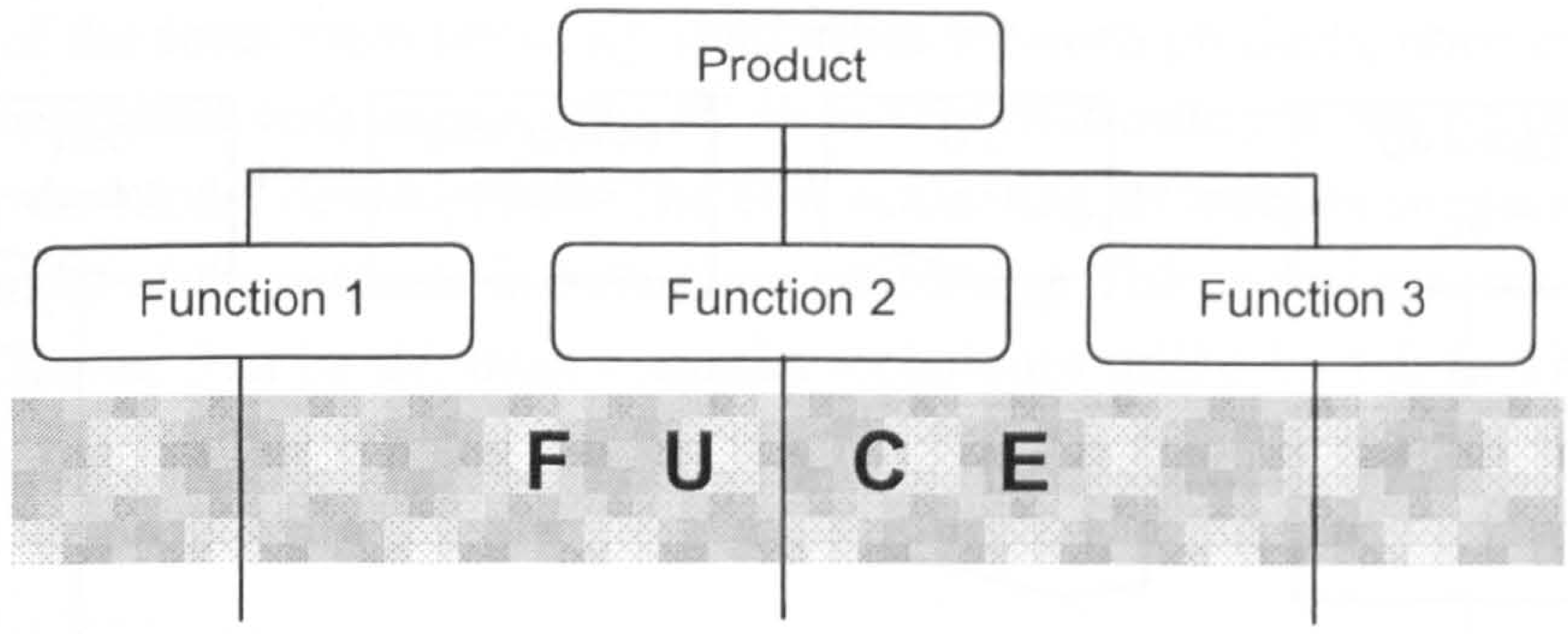


Figure 6-4: FUCE and the commercial facet

Figure 6-3 represents how the CE-E will interact with FUCE. Engineers will be able to provide a cost estimate that has been derived using detailed bottom-up estimating, in a methodological way and which is understood by the commercial estimators and followed throughout the different products or systems. For that to happen, the functional decompositions of the products will have to be agreed in advance between commercial and engineering disciplines within cost estimating.

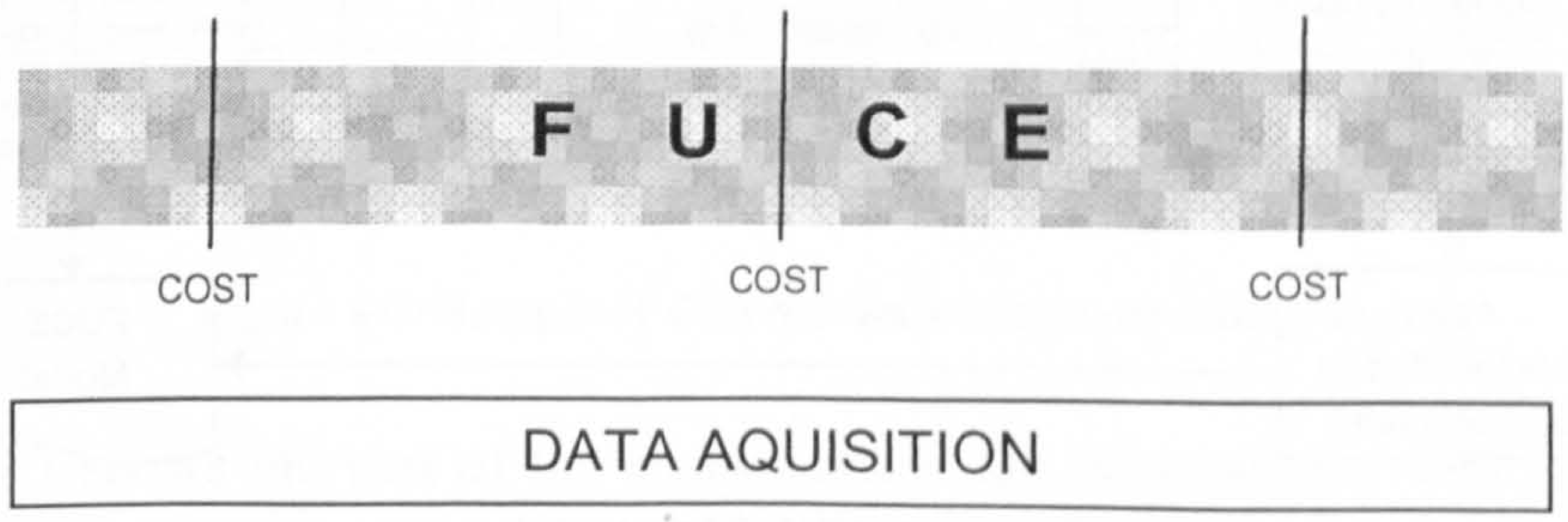


Figure 6-5: FUCE and the engineering facet

Once a function has been established and estimated, there will be no necessity for that function to be cost estimated regularly, thus reducing repeatability of work.

6.2. FUCE Methodology

Methodology

From the model in figure 6-3 follows that the first two stages of the model can be broken down into more detailed, fundamental steps. Figure 6-6 demonstrates the steps of the FUCE methodology:

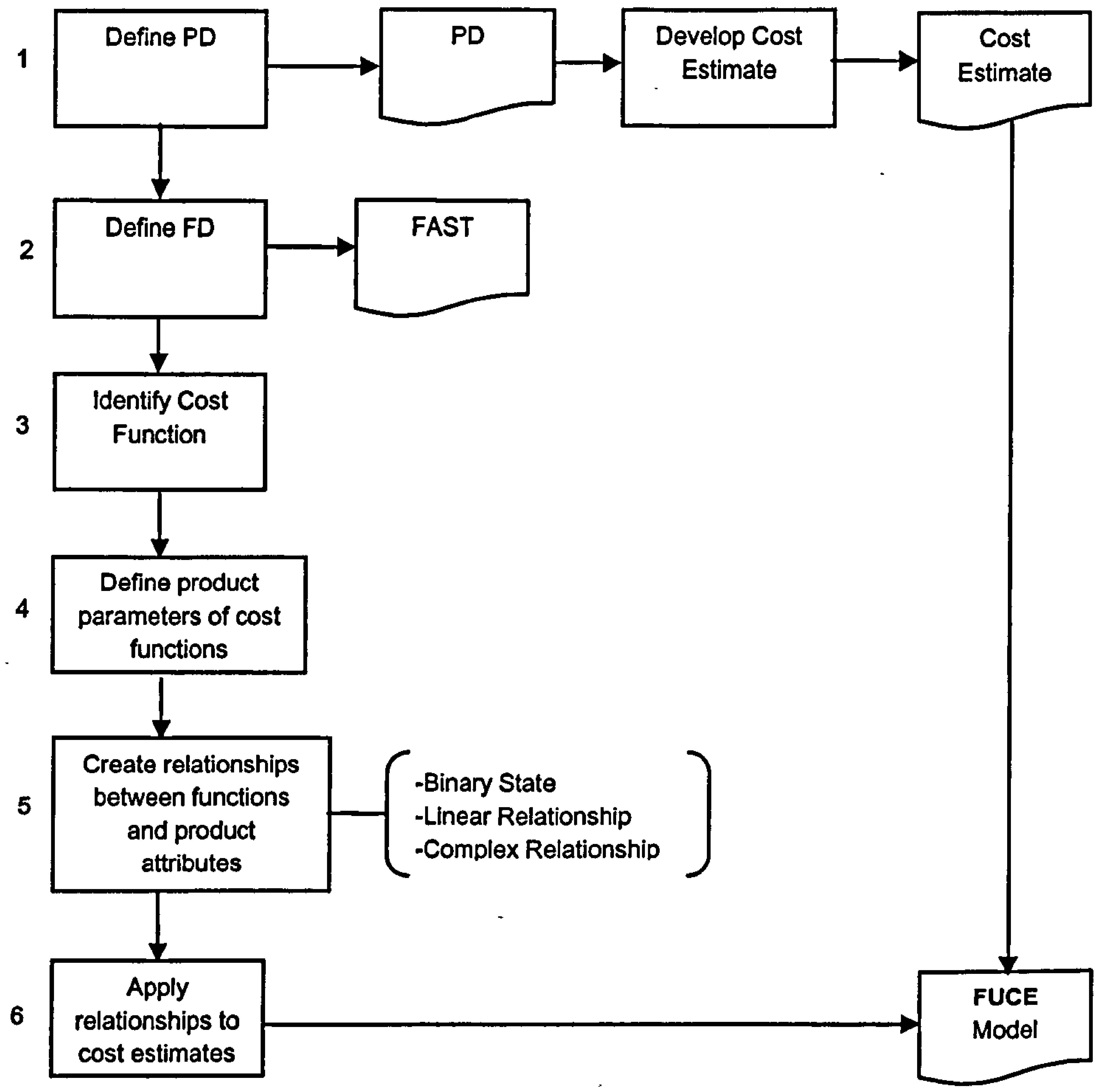


Figure 6-6: FUCE Methodology

6.2.1. Step 1: Define Product Decomposition (PD)

First the PD of the manufacturing good is created. There are a series of reasons for doing this:

1. If the product has not been estimated before, a breakdown can be provided that will allow the experts to develop an estimate;
2. By providing a PD it is easier for the experts to identify the functions of the product;
3. Another possibility could be that many estimates or designs of similar products already exist within the organisation for this specific commodity. In this case the PD can be used to examine the different types of products and conclude to a generic design that represents most of the products.

In most of the cases there are many similarities between products, once an estimate can be associated with ease to the PD then this cost estimate can be used as the basis for the model development. The cost estimating techniques suggested for the development of the estimate is bottom-up estimating. This technique was identified during Chapter 5 to be the most common techniques utilise by CE-E. The way of developing an estimate using this technique is discussed in chapter 5 and can be found in appendix C. In summary a detailed estimate will include:

- Material usage and material rates needed to manufacture the final component;
- All the processes and the costs associated to manufacture the component;
- The type of labour (semi-skilled, specialist, etc.), labour minutes and rate needed to manufacture the component.

Description	Code	Flag	Mat Usa	Mat Rate	Man Level	LB G	Lab Mins	Lab Rate	Pieces /Hc	Mat Co	Item Cc	Compc	Manuf Cost
Inlet Pipe													
Part Number: 97BB-5K2													
INSPECTION	2E+06					AA	0	0 7694	150		0 026	DEM	0.026
TACK WELD RENFORCE	7E+06				1	AB	0.1	0 8039	600		0.102	DEM	0.102
END FINISHING MACHME	7E+06					AB	0	0 8039	150		0 088	DEM	0.088
CUTTING MACHINE (anal	7E+06					AB	0	0 8039	150		0.156	DEM	0 156
AUTO TUBE BENDER (2	7E+06	D			1	AB	0.4	0.8039	150		0.322	DEM	0.322
CUT AND FINISH MACHIN	7E+06				1	AB	0.1	0 8039	600		0.106	DEM	0.106
S/S TUBE 409 50 x 1.5 x			0.5	7.15						3 575	3 575	DEM	3.575
SUB							0.6			3.575	4.514	DEM	4.514

Processes — Material Usage — Labour group

Figure 6-7: Sample of detailed bottom-up cost estimating

Figure 6-7 shows the part of the cost estimate that is associated with an exhaust pipe. First the processes like inspection, tack weld, and finishing processes, etc. are calculated, then, the cost of the material is added. The manning for each process is calculated (1) and the type of Labour needed (semi-skilled AA, skilled AB, specialist AS, etc.) is specified using expert judgement.

This type of estimating provides enough detail to construct the relationships as identified later in the methodology between product parameters and functions, for example, material type and usage.

6.2.2. Step 2: Define Functional Decomposition (FD)

The FD allows the users to associate the functions of the product to the PD and therefore to the cost estimate created. With this approach a link is created with

regards to what parts of the product are affected by which functions. The classification will also help the ability to "pick n' much" functions for the system.
For the purpose of this exercise the author decided to use Functional-Analysis System techniques (FAST). The FAST technique has long been used in Value Engineering to analyze costs. But, the method can also be useful in Engineering Design. It is proposed that FAST is a powerful design tactic that can be incorporated in any Systematic Design strategy.

Most Systematic Design strategies such as those of Love (1986) Hubka (1980), and Pahl and Beitz (1984), require the development of the "functional structure" of a technical system early in the design process. The establishment of a functional structure usually comes after the elaboration of the specification and before the search for alternatives. The functional structure is a way of describing the technical system in its most elemental form. It presents the design solution independent of the specific technical methods to be involved.

In most systematic design procedures, the starting point for developing the functional structure is identification of the input-output nature of the system, the "black box" approach. The mechanism for developing the details of the functional structure is presented only in a very general way. A specific tactic is not usually given. The FAST can be an effective tactic for this purpose.

FAST

FAST stands for "**Functional Analysis System Technique**". It was first conceived by Charles W. Bytheway in 1965 (1971), as a way to systematically organize and represent the functional relationships of a technical system. "Function", expressed as verb-noun, has been a fundamental concept of Value Engineering since its inception. Although the concept of function in VE was a powerful tool, until the development of FAST, it served only to focus the attention on the functional aspects of the product and to aid in differentiating between its basic and secondary functions. It divided the product into manageable elements to be dealt with separately. The FAST diagram builds on and extends this concept.
In FAST the functions of the system are identified and displayed graphically with respect to a "how? - why?" relationship (figure 6-8).

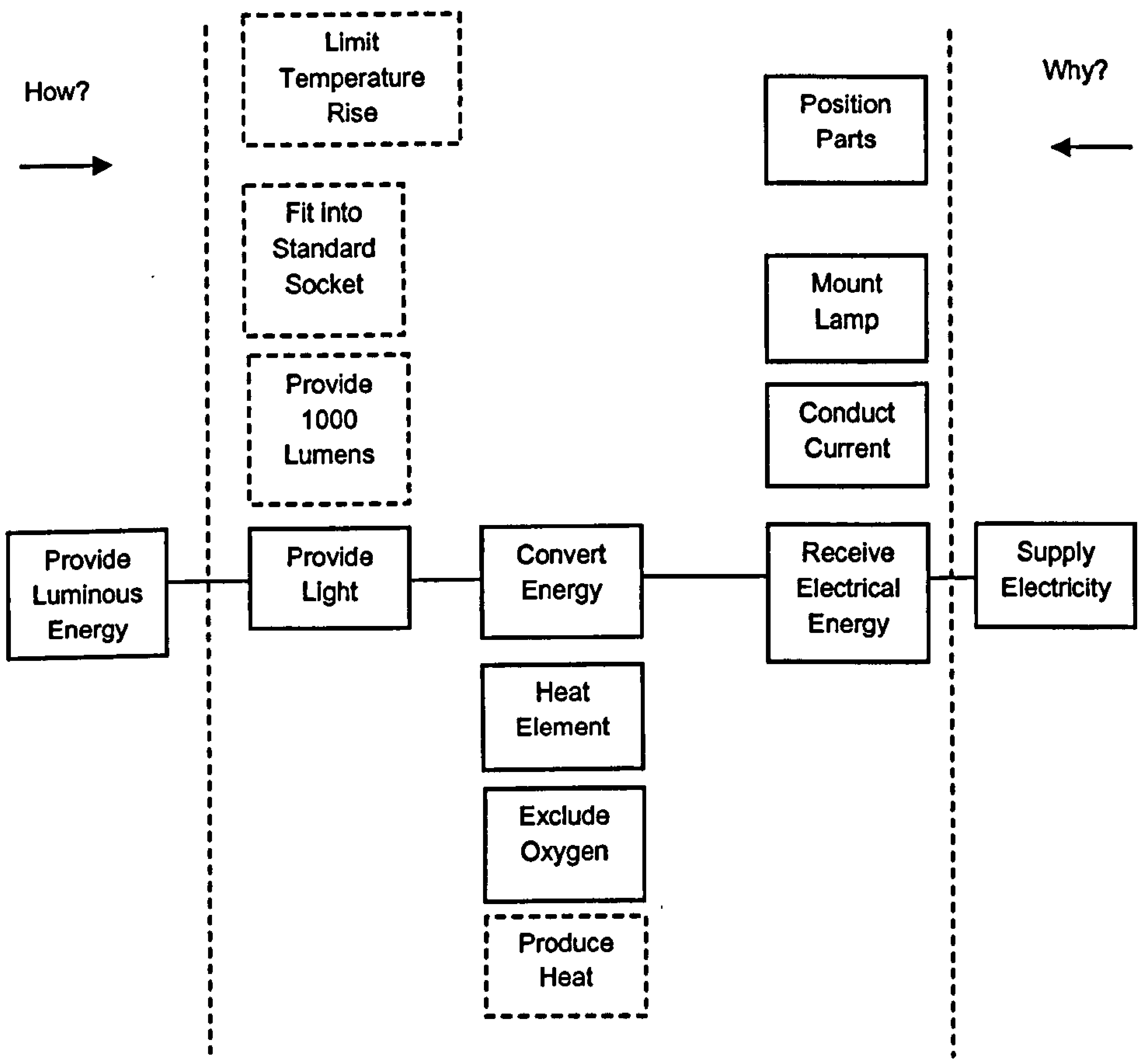


Figure 6-8: Example of a FAST Diagram-Bulb (SAVE, 2001)

BUILDING THE FAST DIAGRAM

To produce a FAST diagram for a technical system, all known "functions" that can be associated with the technical system both internal and external are identified. The functions should be, as in VE, in the form a verb-noun combination (figures 6-9 and 6-10).

The verb should be an action verb (hold, protect, rotate, move, control, direct, etc.), it is the "effect", the "operation" that is performed. Passive or indirect verbs (provide, supply, become, etc.) should be avoided. The verbs describe the "physical effects" that take place within the system.

The noun should be descriptive and general; it is the "operand" on which the operation takes place. These nouns can be conveniently identified as some form of material, energy, information, or abstraction (such as reliability).

Verbs

Absorb	Control	Hide	Minimize	Rotate
Actuate	Convert	Hold	Modulate	Satisfy
AidCreate	Ignite	Mount	Seal	
Allow	Direct	Impart	Move	Secure
Amplify	Ease	Impede	Open	Shield
Apply	Emit	Induce	Position	Shorten
Assist	Emphasize	Inject	Preserve	Space
Assure	Enclose	Instruct	Prevent	Standardize
Avoid	Ensure	Insulate	Promulgate	Steer
Change	Establish	Interrupt	Protect	Support
Close	Exude	Limit	Receive	Suspend
Collect	Facilitate	Locate	Rectify	Time
Comfort	Fasten	Maintain	Reduce	Tolerate
Conduct	Filter	Maximize	Repel	Transfer
Contain	Guard	Mesh	Resist	Transmit

Figure 6-9: List of Verbs for FAST, Ullman (1997)

Nouns

Access	Decoration	Flux	Noise	Task
Odor	Density	Force	Aesthetics	Time
Area	Dependability	Friction	Oxidization	Torque
Care	Deterioration	Heat	Pressure	Dust
Catalysis	Direction	Horsepower	Protection	User
Weight	Uniformity	Image	Radiation	Rust
Color	Emissivity	Information	Repair	Flow
Fluid	Energy	Injury	Variation	Voltage
Current	Vibration	Insulation	Stability	Status
Damage	Corrosion	Light	Volume	

Figure 6-10: List of Nouns for FAST, Ullman (1997)

Names and specific descriptions should be avoided because they limit the choice of creative alternatives. The use of adjectives and adverbs are not used for the same reason. The more elemental terms are the most desirable at the start. This is especially true for the initial functional description of the technical system; later specific names may be usefully added as design decisions are made.

At the beginning it is not essential that the functions be developed in an orderly manner or that they be complete. It has been found that the identification of the functions tend to occur in a somewhat random fashion, as ideas do during the creative phase. At this stage, it is expedient to write out each function on a separate card. During the subsequent spatial re-arrangement of the functions to produce the working FAST diagram, additional functional requirements will present themselves.

In describing an existing technical system, it is easy to identify all the functions. With a new system, it may be necessary to start with the essential functions derived directly from the needs, objectives and specifications for the system.

The functions are classified into basic functions, and secondary (support) functions. The basic functions are those, for which the technical system exists, the basic functions are the functions of the technical system. The secondary functions are all the other functions that are part of the technical system and assist the basic functions. There may also be unnecessary functions in a technical system. In technically oriented FAST, the objective is to determine the one and only basic function. In product oriented FAST, four primary supporting functions are also present; the one that assure dependability, the one that assures convenience, the one that gives satisfaction, and the one that attracts the user. Two arrows are placed at the top of the FAST diagram; one pointing right marked "HOW?", and one pointing left marked "WHY?" The basic and primary supporting functions are selected and placed one above the other to start the FAST diagram, with the basic function uppermost. The remaining functions are arranged to the left or right of functions already on the diagram depending on whether they answer the question "how?" or "why?" If the function is "provide light" the function "convert energy" would go to the right of it because it answers the question "How", the function "provide luminous light" would go to the left because it answers the question "why" (figure 6-8). In Appendix D1 further guidance of how to use FAST is presented.

ADDING A NEW FUNCTION

Although it is not often the case in the automotive industry to have radical changes in the functionality of a commercial vehicle (section 1.1), there is a possibility that a new function might need to be added to a current product. Traditional function decomposition techniques do not accommodate such cases but in the literature review such a method was reviewed. Kirschman (1996) developed a methodology (reviewed in section 2.3.2) called Functional Taxonomy and the author suggests that it can be used successfully to identify the physical attributes of functions. As it can be seen in figure 6-11, the function is broken down into four categories: Power, Motion, Control and Enclosure. By identifying or speculating how this new function can be performed, it is possible to define the physical attributes that are required for the cost estimate.

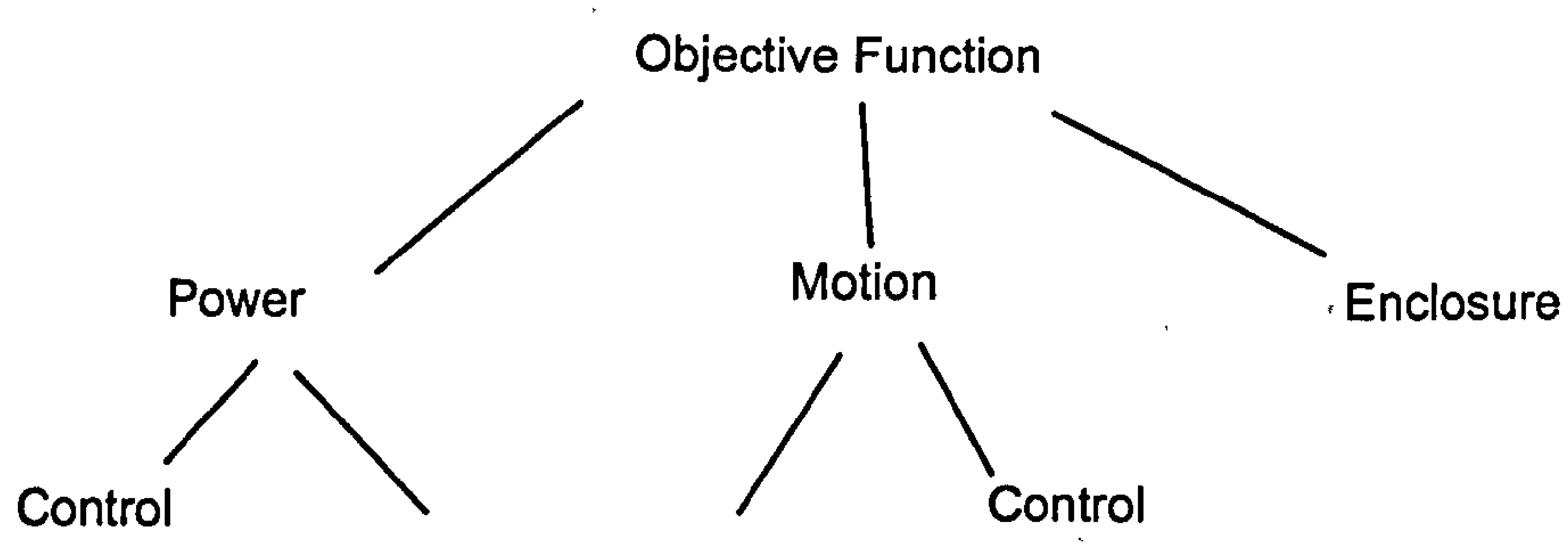


Figure 6-11: Kirschman's Functional Taxonomy (Kirschman, 1996)

6.2.3. Step 3: Identifying Cost Functions

The next step is to identify the cost functions. Cost functions are those that the experts feel affect the cost of the product the most and they vary. By identifying the cost functions, we identify the variables that are going to be used for the model development. This stage is important because as the experts investigate the functions, they can isolate the ones that they want to represent as a constant value in the cost estimate.

The functions that the engineer chooses to analyse further for cost estimating purposes can be from any, or all of the groups mentioned earlier. The Basic and Task functions are a necessary function for the product. The supporting functions affect the cost too as from their nature and are desired but not necessary.

6.2.4. Step 4: Define Product parameters of cost functions

Once cost functions have been acknowledged, the specifications of the vehicle and the physical attributes of the product that affect those functions are identified. To identify those parameters, interviews with the engineers and commercial people are performed. Participants can include varied groups of the organisation like product engineers, tear-down, purchasing, CE-E and CE-C. It is vital to include people with varied background as this creates the opportunity for better results. For example, it is possible that a CE-E can have a certain understanding of how a function has been fulfilled if he has been cost estimating a past product. His understanding is not great enough to warrant an acceptance of his proposition. A product engineer who actually develops similar products like the one under investigation or tear-down people who actually seen competitor's product and experience different solutions to the same problem, can have a valuable input in identifying those physical attributes.

6.2.5. Step 5: Create relationships between functions and product parameters

Now that the cost functions and the physical attributes are established, the next stage is to create a relationship between them. Cost functions can be separated into two types. One is binary, you either have it or you don't. The other is related to performance. In this case the experts need to identify how the values of the attributes associated with the function would change.

- ➢ If the function is equal to a fixed value, the relationship has to be established between the external parameter in the product attributes.
- ➢ If the function has different values, then the relationship is established between those values and the product attributes.

These relationships can either be:

- *Constant*: There is only one value that this function will have. This is usually because that function will represent a "bought out" part or "standard part".
- *Linear*: The relationship may be linear because the design philosophy behind the product has not changed. What will change are the materials used and the size of the product, therefore a linear relationship will be a good a presentation.
- *Complex*: In this case, the relationship is so complicated that is not easy to represent. In such a case the creation of an estimate and further understanding is necessary to understand how this function is affected.

These relationships are either represented by mathematical equations or by tables. The tables are created through eliciting the knowledge of the expert. Examples are presented in Section 6.3 where a case study is developed.

6.2.6. Step 6: Apply relationships to cost estimates

The final step in the methodology is to combine the cost estimate that was decided to be used from step 1 after the PD was identified and relationships were created. Physical attributes that are not affected by the cost functions identified by the experts will have a constant value, for example, all manufacturing processes regarding the manufacturing of a pipe will have a constant cost associated with it. This will form the basis of the estimating model. Then, wherever an attribute is identified in step 4 will be replaced by the relationship developed (mathematical or table) created during step 5. The value used in the estimate will depend on the selection of the dependant variable chosen by the expert.

6.3. Case Study: Exhaust System

In the section 6.2 the FUCE methodology was described by the author. In this section the author demonstrates and validates the methodology using a case study approach.

The case study was completed in a period of four months. The workload and the difficulty of arranging joint meeting for all the participants was a major reason for the long period. Not all the meetings were conducted with the participation of everyone. In total 9 meetings were held, that lasted between half and a full working day. The full details of the participants can be found in section 6.1.1.

The methodology was validated through this case study. In every step, the author explained the procedure and the experts commented based on their experience how useful and easy to understand was each step.

Once the case study was complete the author organised a workshop with the entire group for validation issues. The areas of interest that the author asked the participant to comment were:

- *Performance* (how long does it take to use it and how much data is needed)
- *Accuracy*
- *Ease of Use*
- *Relevance* (Could it be used day-to-day?)
- *Completeness* (Does it cover everything or not)
- *Ease of Adoption*
- *Transferability* (Could it work in every system, e.g. electronics)
- *Improving interaction of CE-C and CE-E*

The actual cost estimating model is developed using MS Excel spreadsheets. Excel was selected because it provided an accessible way for the author to represent the relationships and the tables he would create and then link them to the cost estimate.

The availability of an estimate already in Excel within the company also contributed to that decision.

Scenario

This thesis is concerned with the interaction of CE-C and CE-E at the conceptual design stage. As it has been demonstrated in the introduction of the thesis, in chapter 4 and again discussed in section 6.1, CE-C will request an estimate at the conceptual design stage. That request will be in *unquantifiable* terms, and will be quite vague. The "input" for the CE-E to deal with the request will be a sentence with very limited information, which usually will refer to the *specifications* of the product. The CE-E although they have the ability to produce an estimate once a design or a physical part is available; they find it difficult to face such request.

Typical request will include:
How much will the exhaust system cost...:

a) "...in a small car (class A) with a small engine/1.0 litre?"
b) "...in a small car with a large engine/2.0 litre?"
c) "...if we try to improve the life of the component from 2 to 5 years?"
d) "...if we fit in a large car (class D) a small engine/1.6 and want to have two tailpipes to make it look better"

The author specifies the engine size in the formulation of his questions. It has to be noted that in many cases the request would not even provide such information, it will be just "small engine", "large engine".

Following the methodology, the author will try to answer questions a) to d).

6.3.1. Description of an Exhaust System

Muffler

Exhaust gases leave the engine under extremely high pressure. If these gases escaped directly from the engine the noise would be tremendous. For this reason, the exhaust manifold sends the gases to a muffler (figure 6-12) where they go through metal plates, or tubes, with a series of holes. The pressure of the gases is reduced when they pass through the muffler, so they go out of the tail pipe quietly. The muffler is made of metal and is located underneath the body of the car. It's connected between the tail pipe and the catalytic converter.

There are two types of muffler design. One type uses several baffled chambers to reduce noise. The other type sends the gases straight through a perforated pipe wrapped in metal or fibreglass. This type of muffler is designed for the purpose of reducing back pressure and, consequently, makes slightly more noise.
Since a muffler cannot reduce the noise of the engine by itself, some exhaust systems also have a resonator. Resonators are like little mufflers, and are usually the "straight through" type. They are added at the end of the exhaust system to take care of any noise that has made it through the muffler.

The muffler quiets the noise of the exhaust by "muffling" the sound waves created by the opening and closing of the exhaust valves. When an exhaust valve opens, it discharges the burned gases at high pressures into the exhaust pipe, which is at low pressure. This type of action creates sound waves that travel through the flowing gas, moving much faster than the gas itself (up to 1400 m.p.h.), this is what the muffler must silence. It generally does this by converting the sound wave energy into heat by passing the exhaust gas and its accompanying wave pattern, through perforated chambers of varied sizes. Passing into the perforations and reflectors within the chamber forces the sound waves to dissipate their energy.

<u>The Tailpipe</u>

The tailpipe is a long metal tube attached to the muffler. It sticks out from under the body of a car, at the rear, in order to discharge the exhaust gases from the muffler of the engine into the air outside the car.

<u>Exhaust Pipe Hangers</u>

Hangers hold the exhaust system in place. They give the system flexibility and reduce the noise level. The hanger system consists of rubber rings, tubes and clamps.

<u>Catalysts</u>

The materials within a catalytic converter vary between cars. Catalytic converters are designed to do different things, depending on the design of the converter. Some catalytic converters use what is called an "oxidation" catalyst; this usually consists of ceramic beads coated with platinum to reduce hydrocarbons and carbon

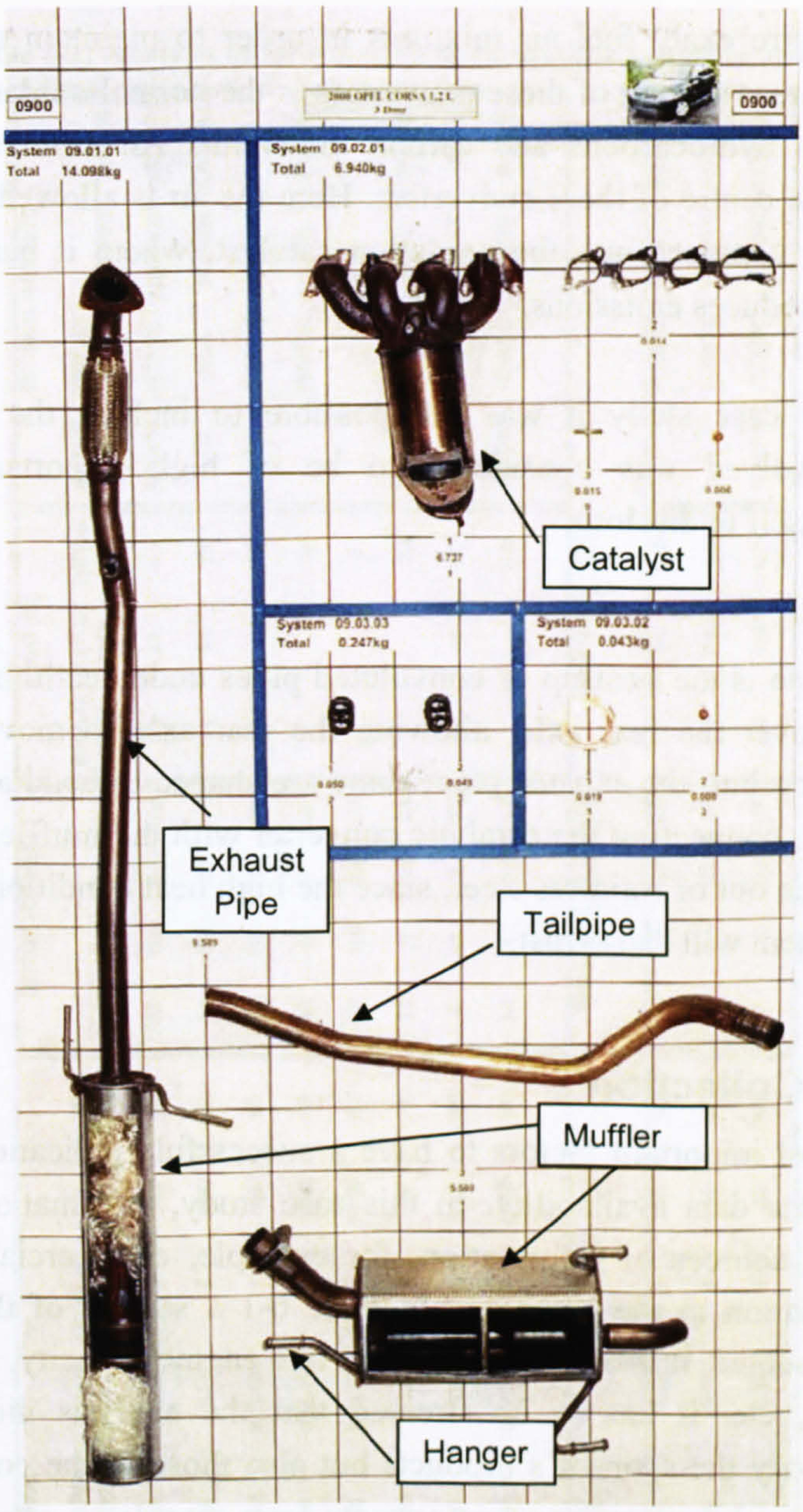


Figure 6-12: An Exhaust System

monoxide. Through the catalytic action, the hydrocarbons and carbon monoxide are "burned" to create water vapour and carbon dioxide. This type of catalytic converter needs an input of oxygen, so oxygen is usually injected into the cylinder head, or directly into the exhaust header or manifold.

Newer catalytic converters have a two part design. The front half is a "three-way" catalyst, which burns various pollutants, and reduces hydrocarbons, carbon monoxide, and oxides of nitrogen into water, carbon dioxide and nitrogen. These converters require exact fuel air mixtures in order to maintain efficient exhaust reduction. The rear section of these converters is the normal oxidation catalyst that further reduces hydrocarbons and carbon monoxide. Air from the air pump is injected into the centre of these converters. Here the air is allowed to mix with the exhaust before it passes into the oxidation catalyst, where it burns off its toxic chemicals and reduces emissions.

NOTE: In the case study it was not possible to include the catalyst as the technology involved was considered to be of high importance to the car manufacturer itself to disclose.

Exhaust Pipe

The exhaust pipe is the bent-up or convoluted pipes underneath the car. Some are shaped to go over the rear axle, allowing the rear axle to move up and down without bumping into the exhaust pipe; some are shaped to bend around under the floor of the car, connecting the catalytic converter with the muffler. Exhaust pipes are usually made out of stainless steel, since the high heat conditions involved with the muffler system will cause rust.

6.3.2. Data Collection

One of the most important factors to have a successful application of the FUCE framework is the data availability. In this case study, information was gathered using different sources of information, for example, commercial magazines, or internal information to the company. In table 6-1 a sample of the relevant data analysed is presented, it includes information like engine capacity, muffler volume, materials used, etc. it has to be stressed that the analysis did not take into consideration only the sponsor's products but also those of the competition. Thus data was acquired by examining components from tear-down exercises (figure 6-13). In this case, the researcher had the opportunity to have an interaction with the physical components and take measurements at first hand.

This type of information is needed in order to create the relationships between the functions and the physical attributes of the product (see section 6.2.8).

Table 6-1: Analysis of information of competitor's muffler systems

BENCHMARK SUMMARY, FIESTA RIVALS PETROL

GENERAL							MUFFLER VOLUME (L)				WEIGHT (KG)			EXTERNAL MATERIALS			
VEHICLE	YEAR	INTERPIPE O/D (mm)	DE COUPLER	No. of HANGERS	T/P VISIBLE	T/P STIFFENER	FRONT	REAR	TOTAL	xESW	MUFFLER FRONT	MUFFLER REAR	SYSTEM TOTAL	MUFFLER FRONT	MUFFLER REAR	INTERPIPE	TAILPIPE
GM CORSA 1.0 12v	2000	38	FLEX	5	YES	NO	7.1	11.3	18.4	10.4	4.5	5.4	9.9	FERRITIC	FERRITIC	AUSTENITIC	AUSTENITIC
GM CORSA 1.4 16v	2000	45	FLEX	5	YES	NO	5.4	11.3	16.7	11.9	4.4	5.1	9.5	ALUM	ALUM	FERRITIC	AUSTENITIC
MERCEDES A 160	1998	41.5	BALLJOINT	3	NO	NO	N/A	11.5	11.5	7.2			10		FERRITIC	FERRITIC	FERRITIC
NISSAN MICRA 1.0	1999	38	BALLJOINT	5	YES	NO	N/A	6	6	5.9			18		FERRITIC	STEEL	AUSTENITIC
PEUGEOT 206 1.1	1998	42	BALLJOINT	3	YES	NO	N/A	12.5	12.5	11.4			7				
RENAULT CLIO 1.4	1998	47.5	FLEX	2	NO	NO	2.2	11	13.2	9.4			15.8	ALUM	ALUM	STEEL	FERRITIC
SKODA FABIA 1.4	2000	45	FLEX	5	NO	NO	4	18	22	15.7	3.4	8.1	11.5	ALUM	ALUM	FERRITIC	ALUM
TOYOTA YARIS 1.0	1999	36	BALLJOINT	4	YES	NO	2.6	9	11.6	11.6			10.46	FERRITIC	FERRITIC	FERRITIC	FERRITIC
	Mean Value =	42	Mean Value =	4			Mean Values =		13.9	11.3	Mean Value =		12.7				
B2XX 1.3 RoCam	2002	42	FLEX	3	NO	NO	-	12.5	12.5	9.8	N/A	5.95	10.85		FERRITIC	FERRITIC	AUSTENITIC
B2XX 1.4 Sigma	2002	42	FLEX	3	NO	NO	-	12.5	12.5	8.9	N/A	5.45	10.35		FERRITIC	FERRITIC	AUSTENITIC
B2XX 1.6 Sigma	2002	45	FLEX	4	NO	NO	3	12.5	15.5	8.7	2.00	5.65	12.35	FERRITIC	FERRITIC	FERRITIC	AUSTENITIC

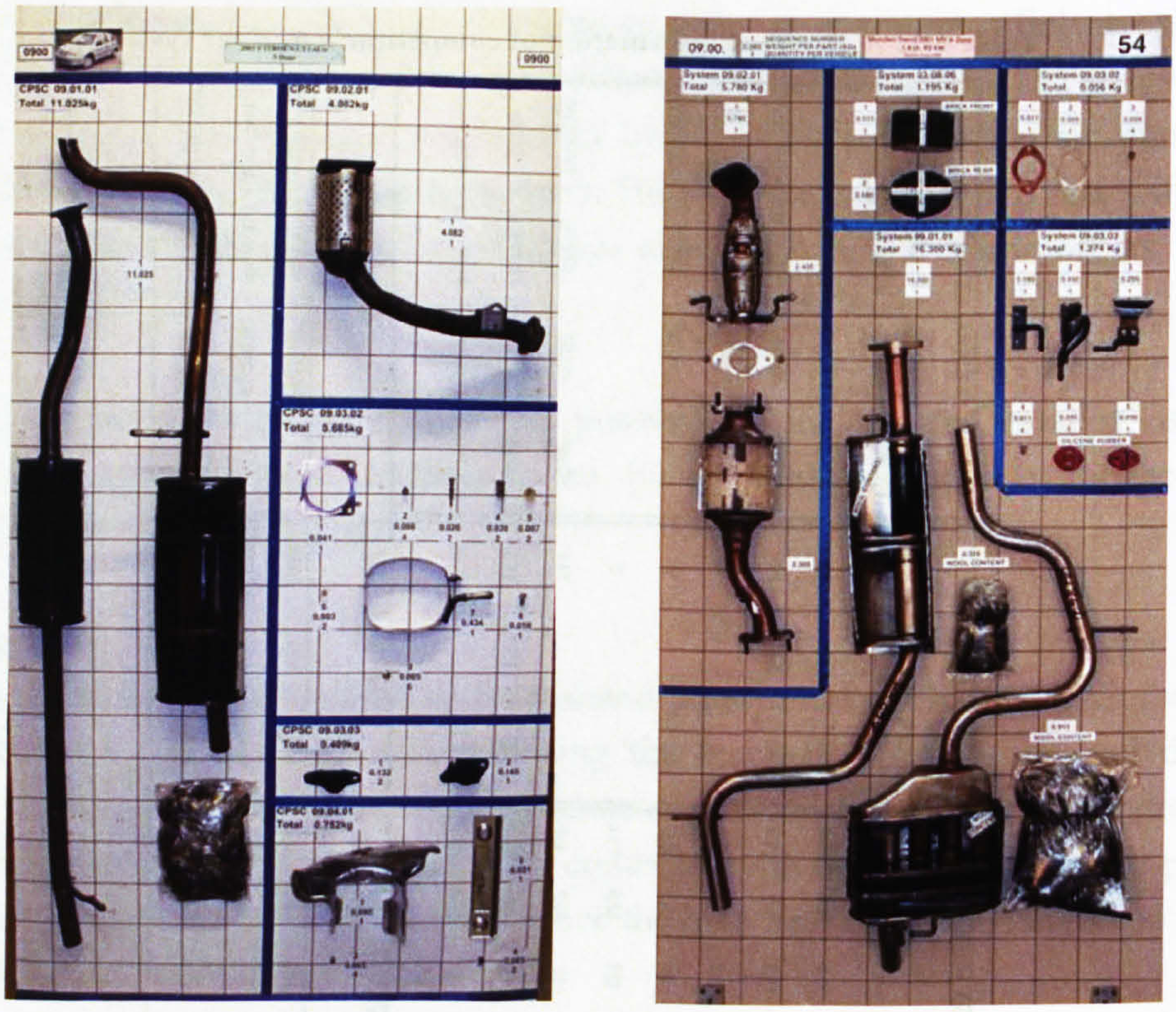


Figure 6-13: Exhaust system samples from Tear-Down activity

6.3.3. Define Product Decomposition (PD)

The first step was to identify the PD. This was done by analysing the same type physical part, looking at past estimates and by consultation between the experts. In this case the organisation had already developed a cost estimate for one of the exhaust systems. The objective was to try and create a "basic" cost estimate (a template), an estimate that could be manipulated later using the relationships that would be created. Figure 6-14 below, demonstrates the PD of a muffler system of a car.

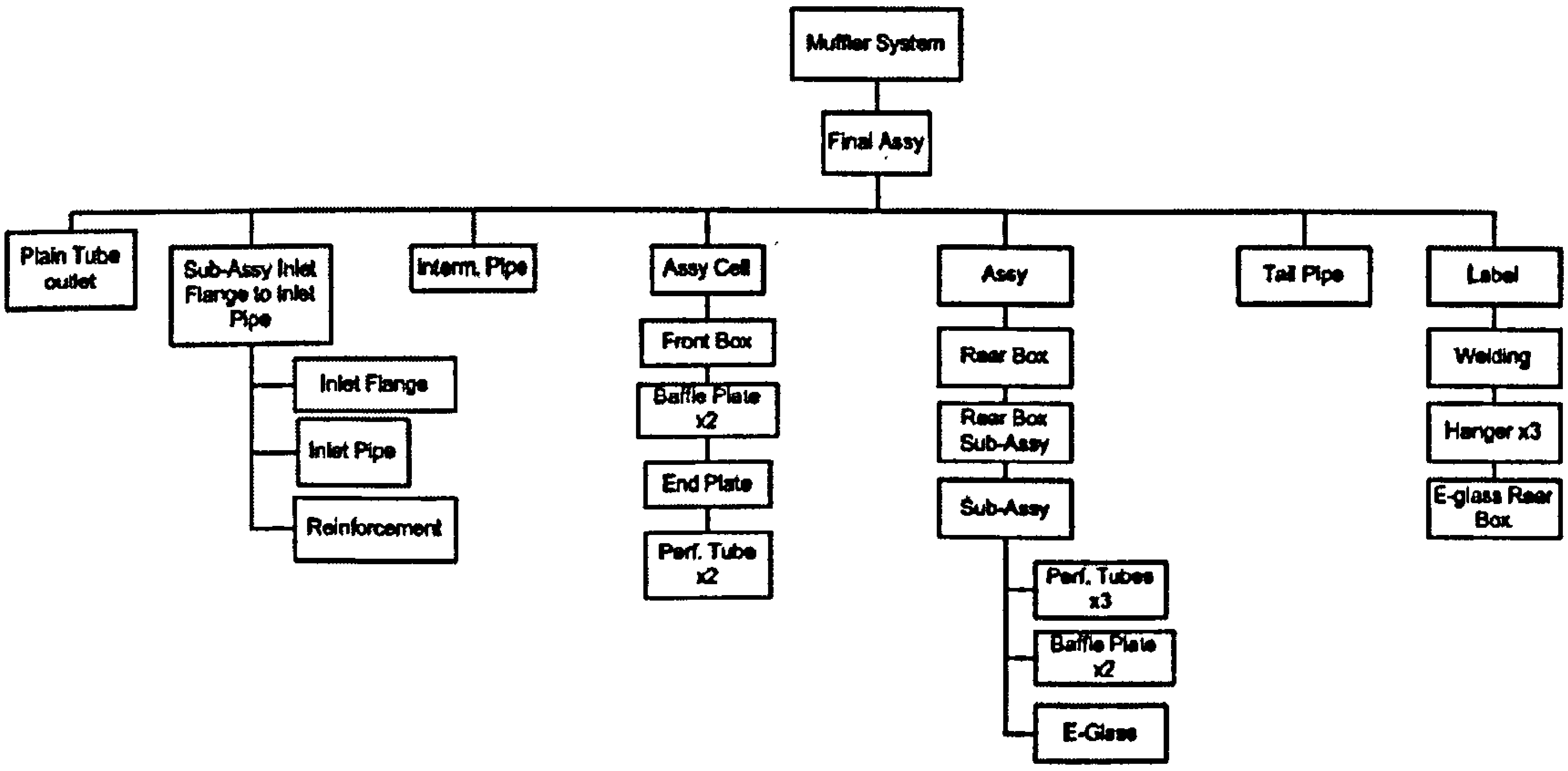


Figure 6-14: Product Decomposition of a muffler system

Based on all the above an estimate was created which is available in appendix D2. Figure 6-15 presents just a 'snapshot of that estimate.

Assy (	Description	Code	Flag	Mat Usa	Mat Rate	Man Level	LB G	Lab Mins	Lab Rate	Pieces /H	Mat Co	Item C	Compc	Manuf Cost
0	Inlet Stub pipe (50 x 1.5 (													
	Part Number: 97BB-5K2													
	INSPECTION	2E+06					AA	0	0.7694	600		0.006	DEM	0.006
	END FINISH (both ends)	7E+06					AB	0	0.8039	300		0.044	DEM	0.044
	END SIZE MACHINE (one	7E+06				1	AB	0.2	0.8039	300	.	0.198	DEM	0.198
	CUT AND END FINISH MA	7E+06				1	AB	0.1	0 8039	600		0.106	DEM	0.106
	SUB							0.3			0	0.355	DEM	0.355
0	Inlet Flange			1	1.5						1.5	1.5	DEM	1.5
0	Inlet Pipe													
	Part Number: 97BB-5K2													
	INSPECTION	2E+06					AA	0	0 7694	150		0 026	DEM	0 026
	TACK WELD RENFORCE	7E+06				1	AB	0.1	0 8039	600		0.102	DEM	0 102
	END FINISHING MACHINE	7E+06					AB	0	0 8039	150		0 088	DEM	0.088
	CUTTING MACHINE (snal	7E+06					AB	0	0 8039	150		0.156	DEM	0.156
	AUTO TUBE BENDER (2 (	7E+06	D			1	AB	0 4	0 8039	150		0.322	DEM	0 322
	CUT AND FINISH MACHIN	7E+06				1	AB	0.1	0 8039	600		0.106	DEM	0.106
	S/S TUBE 409 50 x 1 5 x			0.5	7.15						3 575	3.575	DEM	3 575
	SUB							0 6			3 575	4.514	DEM	4.514
0	Intermidiate Pipe													
	Part Number: 97BB-5K2													
	INSPECTION	2E+06					AA	0	0 7694	55		0.07	DEM	0 07
	END FINISHING MACHINE	7E+06					AB	0	0 8039	55		0.242	DEM	0 242
	END SIZE (Both Ends)	7E+06					AB	0	0 8039	55		0.242	DEM	0 242
	CUTTING MACHINE	7E+06					AB	0	0 8039	55		0.428	DEM	0 428
	AUTO TUBE BENDER (7 (	7E+06	D			1	AB	1 6	0 8039	38		1.286	DEM	1.286
	CUT AND FINISHING MA(	7E+06				1	AB	0.1	0 8039	600		0.106	DEM	0 106
	S/S TUBE 409 50 x 1.5 x			2 48	7.15						17.73	17.73	DEM	17.732
	SUB							1.7			17.73	21 05	DEM	21 046
0	REINFORCEMENT													
	Part Number: 97BB-5K2													
	INSPECTION	2E+06					AA	0	0.7694	600		0.008	DEM	0 008
	END FINISHING MACHINE	7E+06				1	AB	0.1	0 8039	600		0.102	DEM	0.102
	CUT AND FINISHING MA(	7E+06				1	AB	0 1	0 8039	600		0.106	DEM	0.106
	S/S TUBE 409 53 X 1.0 X			0.047	5 44						0 256	0 256	DEM	0.256
	SUB							0 2			0.256	0.47	DEM	0.47

Figure 6-15: Snapshot of muffler estimate

Due to the size and the complexity of the estimate, the author will present the case study with only a summary of the cost estimate. A much friendlier version is presented here to demonstrate the case study (figure 6-16).

Item	Cost (£)
Pipes	---
Front Muffler	---
Rear Muffler 1	---
Rear Muffler 2	---
E-Glass	---
Assembly Costs	---
Other Costs	---
Total Cost	---

Figure 6-16: Basic Cost Estimate

As discussed, above but also in section 6.2.1, the estimate had to be generic. During the analysis of the data, it was observed that a small amount of products were designed with two rear mufflers and two exhausts. This was usually found in big cars or sports cars. Therefore the estimate used had to accommodate for the possibility of two mufflers and two tail pipes. It was decided by the team that a rule will need to be created to make the decision when to use two or one rear muffler

6.3.4. Define Functional Decomposition

The next step in the methodology was to identify the functions of the product under investigation. Functions are usually associated with verb-noun relationships (see literature review, section 2.3.2 and section 6.2.2); this provides a particular advantage in trying to explain to commercial people the reasoning behind the need of a product or component. For example, in the case of the exhaust system one of the primary functions of the car is to transfer gas to the rear of the vehicle. Another one is to control the noise. By associating functions and elements of the PD, a better explanation can be provided to the CE-C, so they can understand why certain elements of the product are there. The depth of analysis performed in order to examine and document the functions, depends on the accuracy you try to achieve, on the costing data available to you and the size/number of components of the sub-system under investigation. To perform the analysis of the car as a whole, it would be extremely difficult and time consuming. Figure 6-17 presents the functional decomposition of the exhaust.

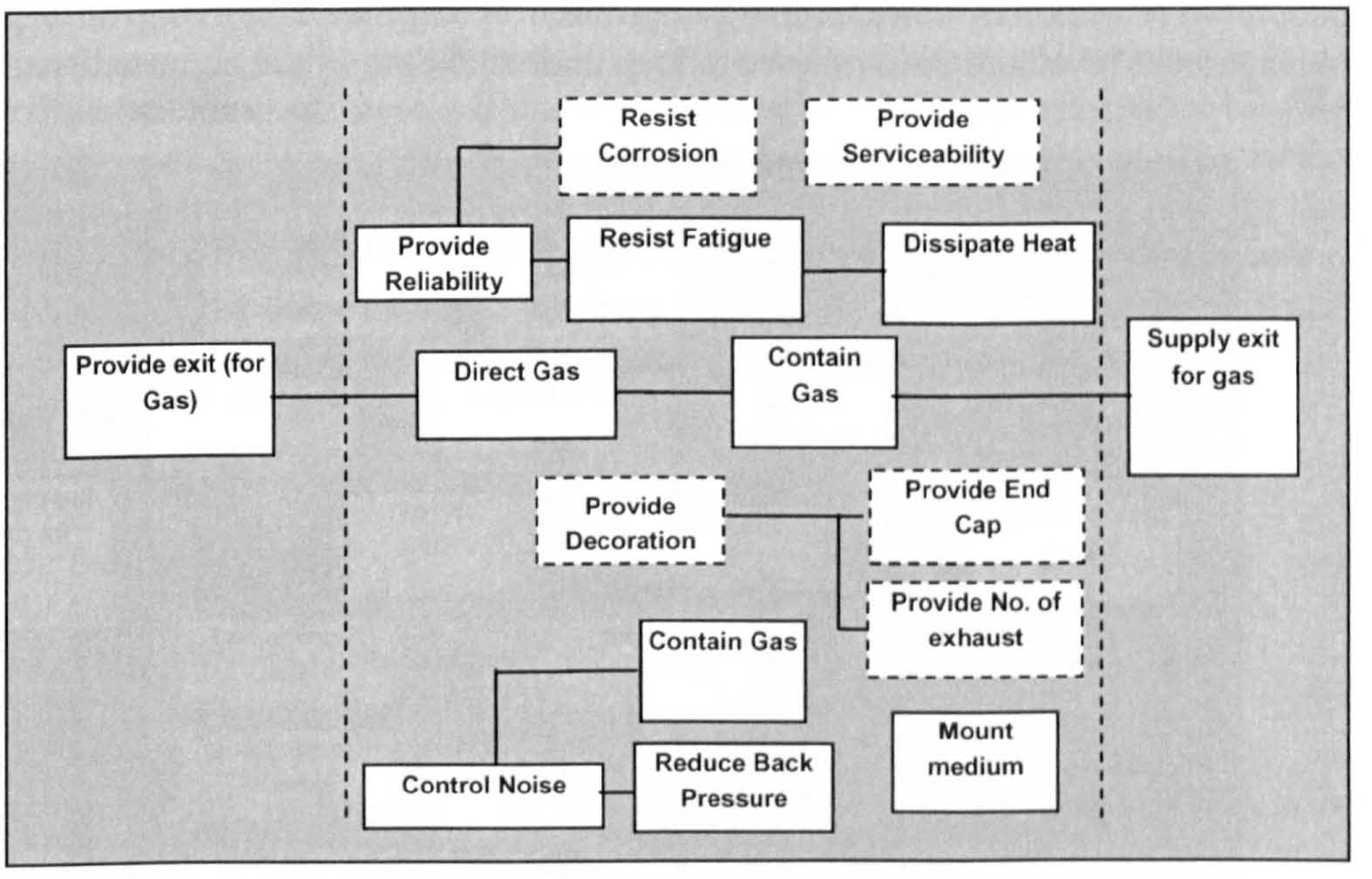


Figure 6-17: Functional Decomposition of the exhaust System

On appendix D1 a guide is presented to assist the experts to the development of the FAST diagram.

6.3.5. Identify cost functions

Figure 6-17 demonstrates the functional decomposition of the muffler system. The cost functions of the product are highlighted as recognised by the engineering people. To identify which functions to cost, the functions that affect the product cost significantly are selected. At a later stage, once the cost estimate has been created the CE-E can verify if indeed the selections they made were the correct once and if not make amendments.

The functions identified in this case study are the following:

1. Provide exit
2. Control noise
3. Provide Reliability
4. Provide Decoration

These functions were selected based on expert judgement by the commercial people as the most important and the ones that affect the cost the most. It was then confirmed by the CE-E.

Throughout the development of the case studies it was observed that some groups of people had difficulty in identifying the functions of the product. Usually these people were either of commercial background or engineers working on a project management level and did not have a deep understanding of the commodity.

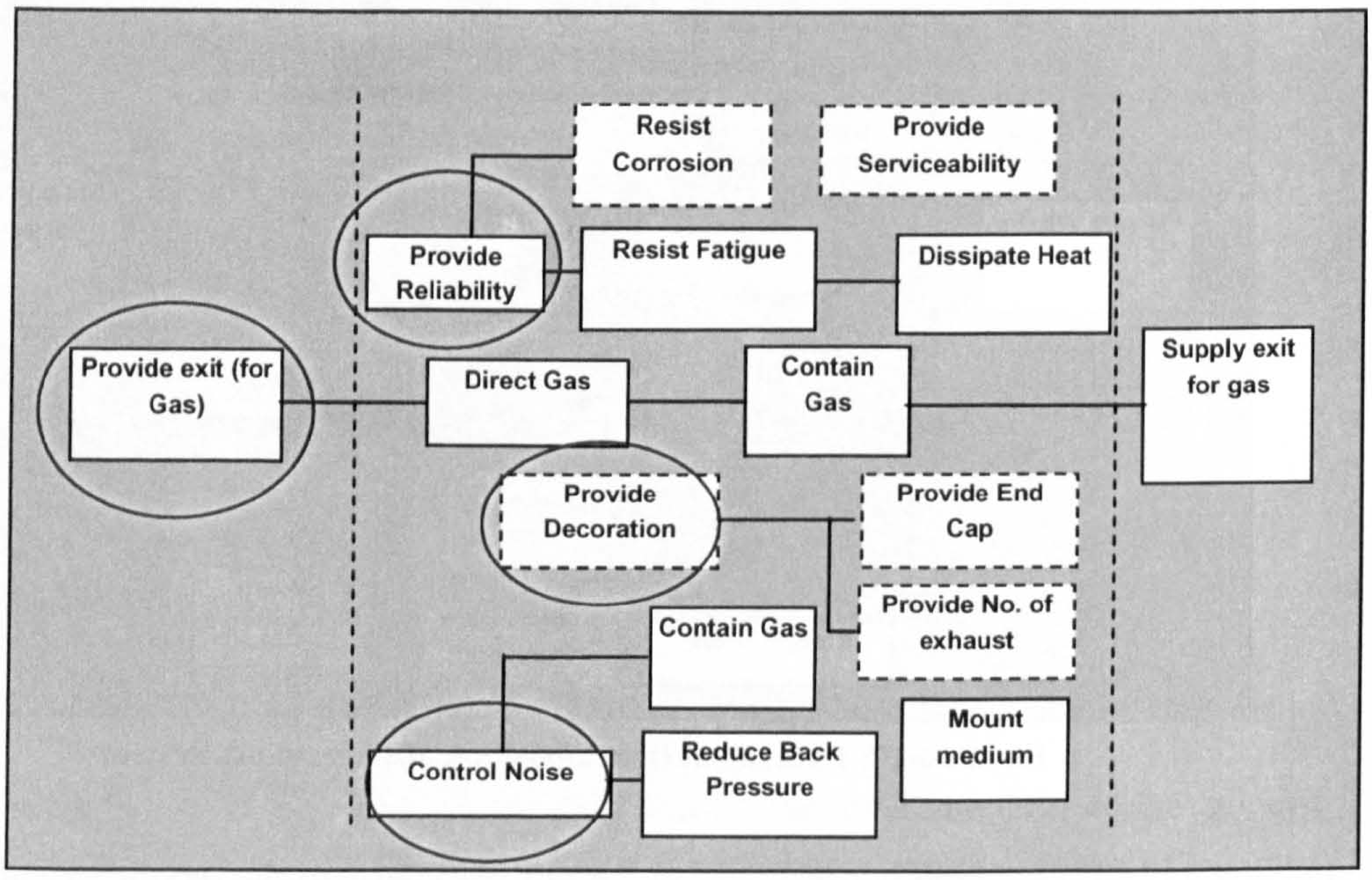


Figure 6-18: Functional Decomposition of Muffler System

6.3.6. Define product attributes of functions

Once cost functions were acknowledged, the product parameters and the specifications that affect those functions were identified. For example, in the case of *control noise* and *provide reliability* functions, the engine size and the lifetime were identified as the specifications that affect those functions. The physical characteristics that affect them are presented in figure 6-18.

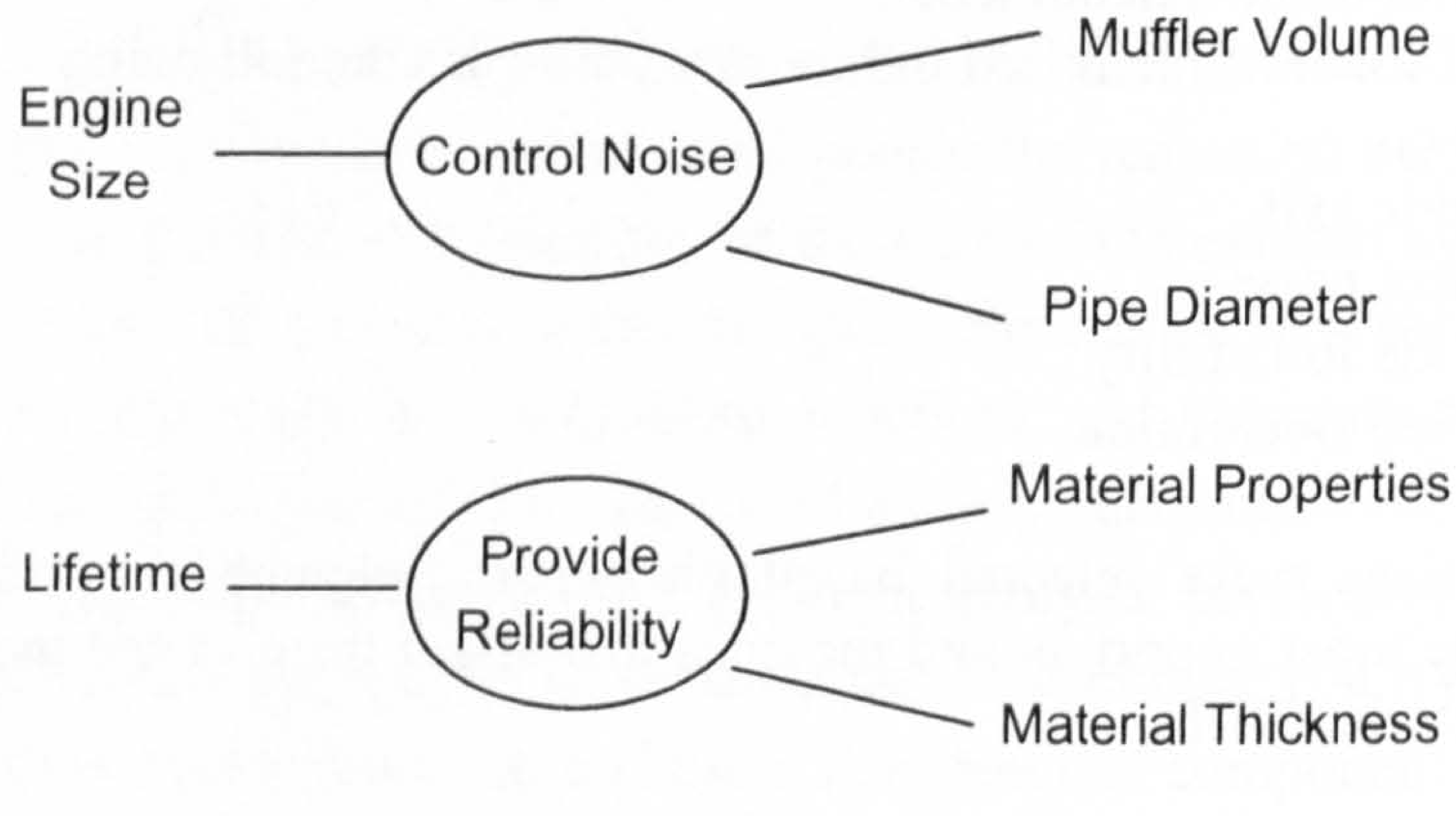


Figure 6-19: Product attributes

To identify these parameters, interviews with the engineers and commercial people were performed. It has to be noted that in many cases commercial estimators had a better understanding of these parameters and how they change compared to other engineering groups e.g. future product developments. The reason for that is that commercial people within cost estimating try to expand their knowledge and understanding across different engineering sub-systems and get an overall view of the product. On the other hand the engineering groups are usually associated with a specific subsystem and are used to the type of solutions they already know.

In summary, the specifications identified for each cost function were:

Provide Exit → Car Size
Control Noise → Engine Size
Provide Reliability → Lifespan
Provide Decoration → Type of vehicle, No. of exhausts

For example, the reason for specifying the engine size in the control noise functions was identified by expert judgement. The bigger the engine the more noise it will produce.

Those specifications will form the inputs to the cost estimating model that will be built in the next stages. The users (CE-C, CE-E, engineers, etc.) will be able to define their specification of the vehicle and will get as a result a cost estimate for the muffler system that will satisfy the specifications.

Finally, the attributes for the functions of the muffler system are presented in Table 6-2.

Table 6-2: Physical attributes of functions of the muffler

Function	Physical Attributes
Provide exit	-Length
Control noise	-Muffler Volume -Pipe diameter
Provide Reliability	-Material Properties -Material Thickness
Provide Decoration	-Material Properties -Design Features

6.3.7. Create relationships between functions and product parameters

After the input parameters, the cost functions and the physical attributes were established, the next stage was to create a relationship between them. In the case of the *control noise*, the decision was to satisfy the function, the experts did not want to reduce the output of decibels as other parts of the car would make more noise (tyres), and did not want to increase it as it would bridge the legislation limit. On the other hand *provide reliability* could have different values (one year, two years… up to five years). In this case the author needed to identify how the values of the attributes associate with the function would change depending on the specifications.

The relationships were either represented by mathematical equations or by tables. They were created through eliciting the knowledge of the expert. A series of data analyse available either from the tear-down department or from the engineers (examples in table 6-1 and figure 6-14) were also performed in order to create the relationships. All the relationships in Excel can be found in appendix D3. Below a description of some of the relationships created per functions are presented:

Provide Exit

For this function a relationship was developed based in the examination of different size vehicles and the measured length of piping needed.

Control Noise

For this function a relationship was created, again from data collected, between engine size, pipe diameter, E-glass weight and muffler volume. For example, figure 6-20 demonstrates the relationship between the engine size and the muffler volume.

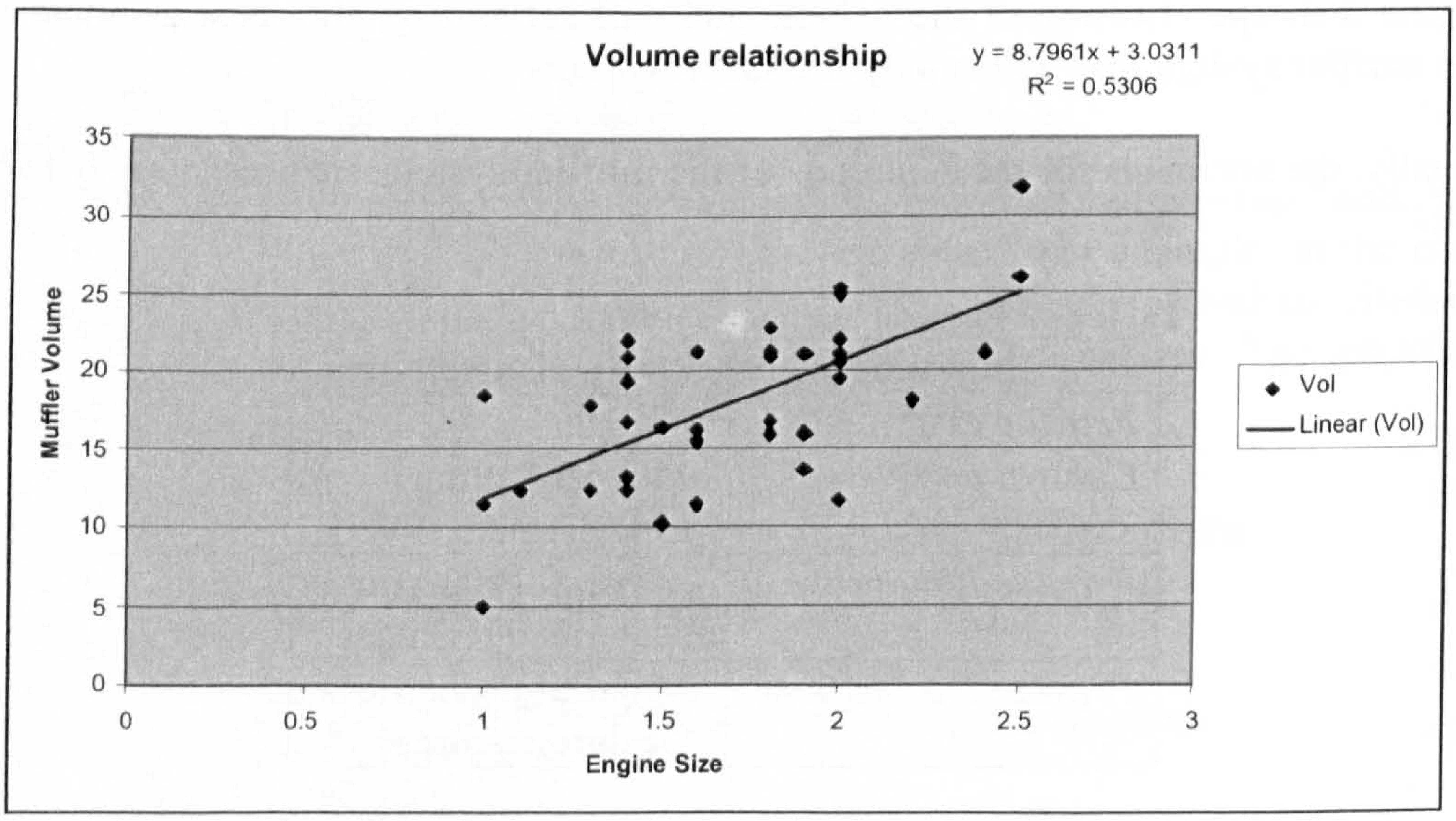


Figure 6-20: Relationship between engine size and muffler volume

It has to be noted that the R^2 value of 0.5306 is not very good. The primary reason for that was due to different philosophies of design from manufacturers. For example, one manufacturer would always design its cars with big front mufflers, as a result, the rear mufflers are always different than other manufacturers who traditionally prefer small front mufflers and big rear ones. When the author plotted data only from the same manufacturers, the R^2 reached up to 0.85.

In addition to the identification of the muffler volume a ratio had to be set between the volume of the front muffler and the rear one. The ratio used for this was 2 (figure 6-21). A radius was also specified for the front a rear muffler (5 centimetres for the front, ten centimetres for the rear).

rear muff rad	1
front muff rad	0.5
reA/FRON RATIO	2

Figure 6-21: Ratio between front and rear muffler

A limit needed to be set also on the maximum volume a car had space below to fit its muffler. Figure 6-22, demonstrates, for example, that for a B-class car (medium size) the rear muffler limit is 12.5 litres and for the front 6.25. For all these relationships and rules, the expert judgement of the participants was utilised together with the data analysis performed from past products.

CLASS	Muffler limit	front Muffler limit
A	10.00	5.00
B	12.50	6.25
C	21.30	10.65
C/D	32.00	16.00
D	40.00	20.00

Figure 6-22: Limits for front and Rear Mufflers

Table 6-3 represents the relationships between the size of the engine, pipe diameter, E-glass material and muffler volume.

Table 6-3: Relationship between multiple variables

ENGINE SIZE	Pipe Dia.	E-Glass Weight	Muffler Vol.
0.8	38	194.94	11.36
1	42	194.52	12.52
1.2	42	225.32	13.98
1.3	42	252.44	14.82
1.4	42	287.35	15.74
1.5	42	330.08	16.74
1.6	42	380.60	17.81
1.8	50	505.08	20.18
2	50	660.78	22.86
2.2	50	847.70	25.84
2.5	54	1186.64	30.88
3	54	1907.64	40.81

Provide Reliability

For this function the relationship was created between different material's properties and thicknesses. Table 6-4 represents the relationships between service life of the component and the material properties and thickness.

A full list of the tables created for this case study, together with the cost estimate can be found on Appendix D4

Table 6-4: Table created by eliciting expert knowledge

Service Life	Material	Thickness
1 year	Mild Steel	1.5
2-3 Years	Al. M. Steel	1.5
4 Years	Med. Grd.Steel	1.2
5 Years	S/S	1

Provide Decoration

This was an aesthetic function and was dictated by the material selection and the design features, in this case that meant different number of exhausts on the back of the car.

It is very important to note that these relationships were created in conjunction with the experts. This allowed the establishment of the relationships and the rules not only on the data available but also on the knowledge of the experts. For example, when specifying the number of rear muffler boxes, there was no data available from current cars on which to base judgement. The engineers within the company provided the rules and the rationale for that. Judgements were made for different volume limits for all the different classes of cars, in order to dictate the number of mufflers needed for the vehicle.

Finally, the interface for the user, where the specifications of the product will be changed was produced (figure 6-23). Once these inputs were established by the experts and the validation was under way to establish the agreement of all parties, an observation was made by the CE-C. They wanted the ability to incorporate some extra functionality to the model with regards to the commercial aspect. Those inputs were the "country of origin" and the "timeframe" when the product will be manufactured. Both of these were added in the input interface and relationships were created, for example the timeframe was related to yearly inflation as represented in figure 6-24. Similar relationship was created for the labour rates of the different production countries. By changing the country of origin the cost of labour will change.

Manufacturing costs were assumed the same for the case study although the experts agreed that modifications will need to be included in the future to accommodate for different manufacturing costs.

The Full list of options the user is able to specify is:

- ✓ how big or small is the car (based on the classification system of the automotive industry);
- ✓ The size of the engine the car will have
- ✓ The desired life expectancy of the system
- ✓ The type of vehicle that is under production
- ✓ The number of exhaust on the vehicle
- ✓ The country were the manufacturing will occur, and finally;
- ✓ How far in the future the product will be produced.

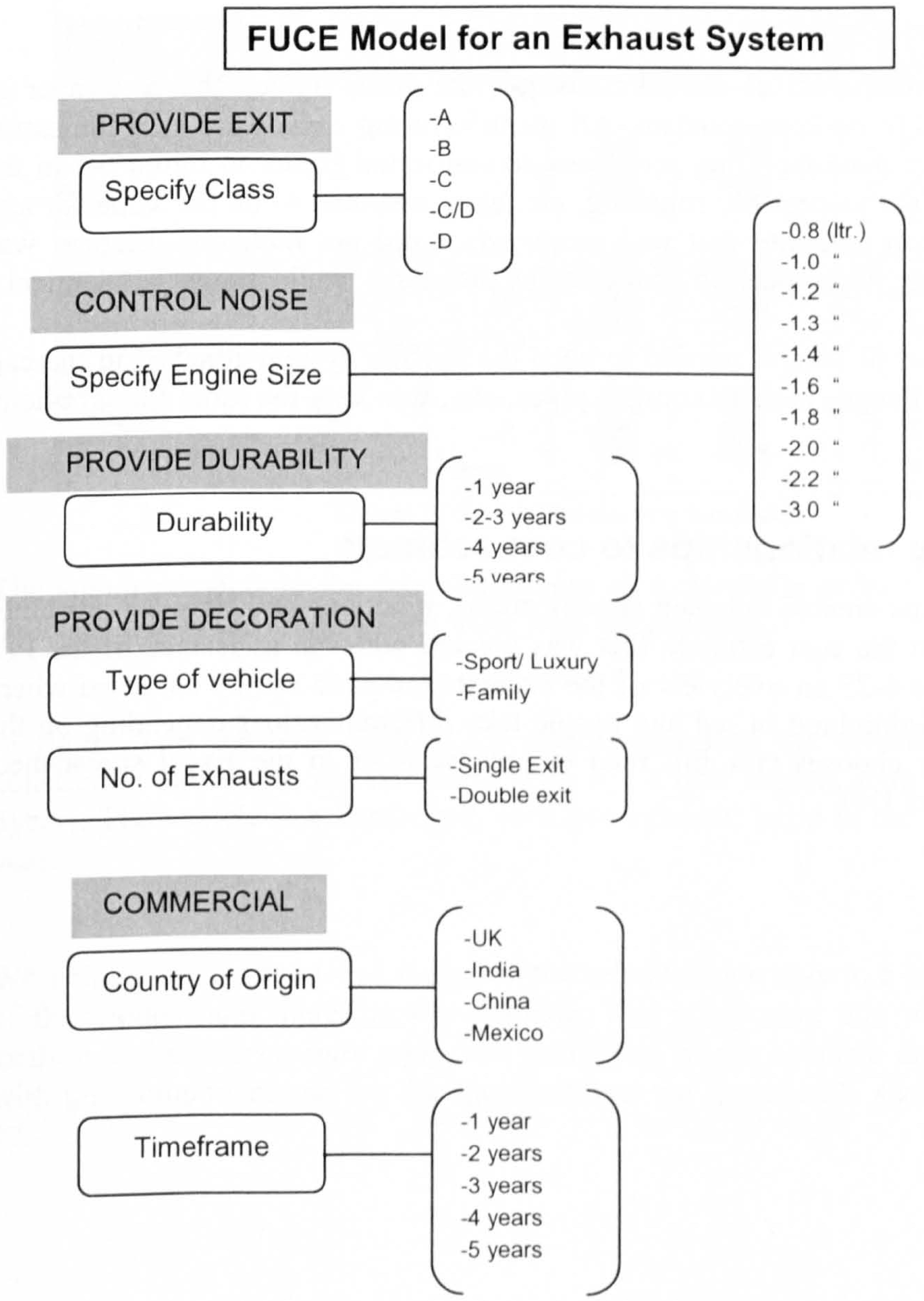


Figure 6-23: The available FUCE Inputs for the exhaust model

Timeframe	Inflation	Cum. Inflation
1y	0.05	1.05
2y	0.06	1.11
3y	0.07	1.19
4y	0.06	1.26
5y	0.05	1.33

Figure 6-24: Time frame and inflation relationship

Assumptions

During the development of the relationships, the group agreed that a number of parameters had to be kept constant. All manufacturing costs were kept the same, for example, the manufacturing processes demonstrated earlier in figure 6-7 in the pipe example like inspection, finishing, etc. were assumed to be the same for any type of pipe cost estimate that was produced. It did not matter if the pipe was longer or shorter, the inspection and finishing processes would almost be identical.

Also the number of hanger needed to keep the muffler system attached to the car, the cost of the flanges need to connect pipes, etc., was kept the same for simplicity purposes.

6.3.8. Apply relationships to cost estimate

The relationships created between specifications, functions and physical attributes were applied to the cost estimate that was created with the assistance of the PD. Below in figure 6-25 an overview of the estimate template can be observed where the elements highlighted in red and purple take different values depending on the inputs the user chooses (for full read out please refer to the Excel spreadsheet model, appendix D4).

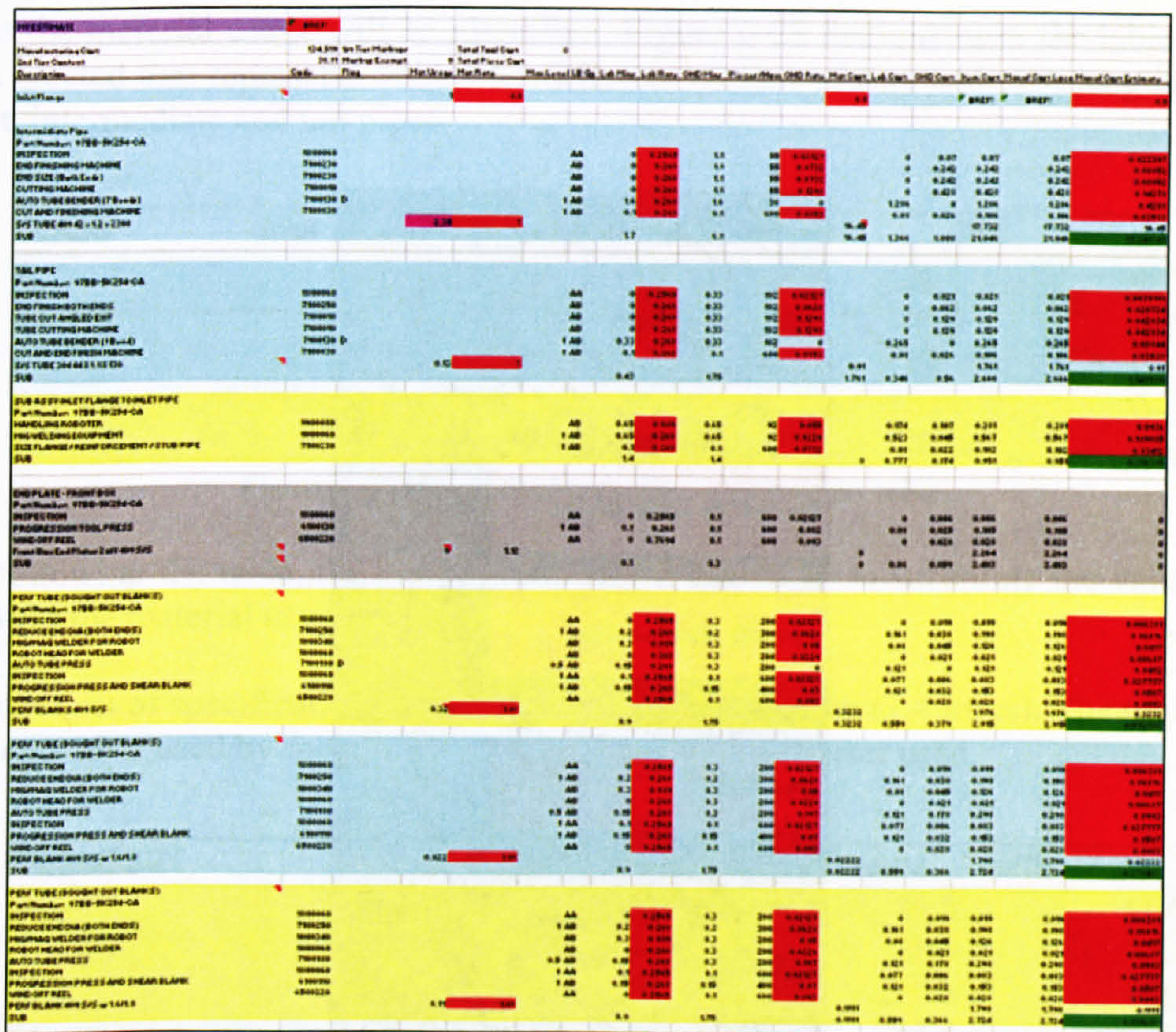


Figure 6-25: Cost estimating template

The author presents in the following pages an example in order for the reader to understand how the relationships work with the estimate.

In figure 6-26 the user chooses the specifications of the vehicle. He wants to construct a small size car (B-class), with a 1.4 litre engine, with a durability of 5years. The vehicle is a family car, with one exhaust; build in the UK in the next year.

We will follow the model as it applies the relationships only to a single small part of the product and therefore the estimate. The component that we are going to analyse is the *intermediate pipe*. The small part of the estimate that is associated with this component and for the specifications we specified is shown in figure 6-27.

Figure 6-26: FUCE Input

Description	Code	Flag	Mat Usa	Mat Rate	Man Level	LB Gp	Lab Mir	Lab Rate
Intermidiate Pipe								
Part Number: 97BB-5K254-C.								
INSPECTION	1800060					AA	0	0.24
END FINISHING MACHINE	7100230					AB	0	0.29
END SIZE (Both Ends)	7100230					AB	0	0.29
CUTTING MACHINE	7100010					AB	0	0.29
AUTO TUBE BENDER (7 Benc	7100130	D			1	AB	1.6	0.29
CUT AND FINISHING MACHIN	7100030				1	AB	0.1	0.29
S/S TUBE			1.95	1.59				
SUB							1.7	

Figure 6-27: The intermediate pipe. Part of the overall estimate

As can be seen the model has attributed the value of 1.95metres for the material usage and 1.59£/metre for the material rate. Also the Labour cost is £0.29/min for a skilled worker (AB) and £0.24 for a semi-skilled worker (AA). In the next couple paragraphs the author will try and identify where these values came from.

First the material usage will be identified. Figure 6-28 demonstrates the table that was created that represents values for different classes of cars and pipe lengths for inlet, intermediate and tail pipes.

CLASS	Inlet	Inter	Tail
A	0.30	1.[illegible]0	0.15
B	0.15	1.95	0.20
C	0.20	1.65	0.15
C/D	0.25	1.85	0.20
D	0.25	2.05	0.30

Figure 6-28: Class of vehicle and pipe lengths table

By following the table, the model identifies that it needs to substitute the value of 1.95 for the material usage.

Another set of specifications set was that of the engine size (1.4 litres). The table in figure 6-29 is used by the model to identify the pipe diameter used.

ENGINE SIZE	Pipe Dia.	E-Glass Weight	Muffler Vol.
0.7	38	39.9	11.4
1	42	165.6	12.5
1.2	42	249.3	14.0
1.3	42	291.2	14.8
1.4	42	333.0	15.7
1.5	42	374.9	16.7
1.6	42	416.8	17.8
1.8	50	500.5	20.2
2.1	50	626.1	22.9
2.2	50	668.0	25.8
2.5	54	793.6	30.9
3	54	1003.0	40.8

Figure 6-29: Table vs. pipe diameter vs. e-glass vs. muffler volume

Also from the table in figure 6-30, the model can identify the material thickness. As was specified the product needs to last for 5 years, the experts had identified that in this case the material needs to be stainless steel of 1mm thickness.

SERVICE LIFE	MATERIAL TYPE	MAT. THICKNESS
1 year	Mild Steel	1.5
2-3 Years	Al. M. Steel	1.5
4 Years	M.Grd.Steel	1.2
5 Years	S/S	1

Figure 6-30: Table of Service Life, material type and thickness

Now that the diameter and the thickness are available the model can substitute from the table in figure 6-31 the correct rate per metre. Because the model was created in Excel description had to be made with numbers, for example, the first column in figure 6-31 represents the different types of pipes. 39.5 is the pipe that has thickness 1.5mm and diameter 38mm, therefore 38+1.5=39.5. Similarly 39 is the pipe that has thickness 1mm and diameter 38mm (38+1=39). For our example we derived so far that the pipe diameter is 42mm and the thickness 1mm. From the table below therefore the value is 43. As we also specified that the material is stainless steel (S/S), the rate that will be used will be 1.59£/metre.

	Cost/metre				
Dia + Thickness	Mild Steel	Al.M. Steel	M.Grd.Steel	S/S	Cr steel
39.5	0.89	0.534	0.356	1.78	3
39.2	0.72	0.432	0.288	1.44	3
39	0.72	0.432	0.288	1.44	3
43.5	0.99	0.594	0.396	1.98	3
43.2	0.795	0.477	0.318	1.59	3
43	0.795	0.477	0.318	1.59	3
51.5	1.185	0.711	0.474	2.37	3
51.2	0.955	0.573	0.382	1.91	3
51	0.795	0.477	0.318	1.59	3
55.5	1.28	0.768	0.512	2.56	3
55.2	1.03	0.618	0.412	2.06	3
55	0.865	0.519	0.346	1.73	3

Figure 6-31: Table of material costs per metre

The inputs specified that the product would be constructed in the UK. Figure 6-32 below specifies the different rates used for different labour categories and countries. In our example those numbers would be 0.24£/min. and 0.29£/min.

LOCATION	AA	AB	AC	AS
China	0.07	0.10	0.11	0.12
India	0.05	0.08	0.09	0.10
UK	0.24	0.29	0.33	0.34
Mexico	0.08	0.11	0.13	0.14

Figure 6-32: Table of Labour Rates

Finally the model would be specified to be constructed in a year's time. The table in figure 6-33 provided the inflation rate that needs to be applied in order to estimate the cost.

Timeframe	Inflation	Cum. Inflation
1y	0.05	1.05
2y	0.06	1.11
3y	0.07	1.19
4y	0.06	1.26
5y	0.05	1.33

Figure 6-33: Table of Timeframe vs. Inflation rates

It needs to be stressed that the labour costs for the different countries and the inflation rates were based on expert judgement for the development of the case study. The experts agreed that for the adoption of the model by their company, a valid source of information would need to be selected.

Similarly to the example demonstrated for the intermediate pipe, other relationships exist that will accommodate for the mufflers the tailpipe, etc. in the model. Because it is not possible to present the results of the full estimates created due to the size of them in the thesis, a summary of the estimate is provided below with the answers to the case study questions. In the introduction of this case study a list of different request were made. Below the questions are provided, followed by an answer. All the estimates are produced using the model created for this case study

Question a: "How much will the exhaust system cost in a small car (class A) with a small engine/1.0 litre?"

INPUT

Specify Class	**A**
Specify Engine Size	**1.0**
Durability	**2-3 years**
Type of Vehicle	**family**
No. of Exhaust	**1**
Country of Origin	**UK**
Timeframe	**1**

Answer:

OUTPUT SUMMARY

Item	**Cost (£)**
Pipes	2.3
Front Muffler	5.5
Rear Muffler 1	8.4
Rear Muffler 2	0
E-Glass	0.82
Assembly Costs	5.8
Other Costs	10.88
Total Piece Cost	**33.7**

<u>Question b:</u> "How much will the exhaust system cost in a small car with a large engine/2.0 litre?"

INPUT

Specify Class	**A**
Specify Engine Size	**2.0**
Durability	**2-3 years**
Type of Vehicle	**family**
No. of Exhaust	**1**
Country of Origin	**UK**
Timeframe	**1**

Answer:

OUTPUT SUMMARY

Item	**Cost (£)**
Pipes	2.9
Front Muffler	5.6
Rear Muffler 1	9.1
Rear Muffler 2	9.1
E-Glass	1.4
Assembly Costs	7.3
Other Costs	9.9
Total Piece Cost	45.3

<u>Question c:</u> "How much will the exhaust system cost if we try to improve the life of the component from 2 to 5 years?"

INPUT

Specify Class	**A**
Specify Engine Size	**1.0**
Durability	**5 years**
Type of Vehicle	**family**
No. of Exhaust	**1**
Country of Origin	**UK**
Timeframe	**1**

Answer:

OUTPUT SUMMARY

Item	Cost (£)
Pipes	4.5
Front Muffler	8.4
Rear Muffler 1	15.6
Rear Muffler 2	15.6
E-Glass	1.4
Assembly Costs	7.8
Other Costs	9.45
Total Piece Cost	**62.75**

Question d: How much will the exhaust system cost if we fit in a large executive car (class D) a small engine/1.6 and want to have two luxury tailpipes to make it look better"

INPUT

Specify Class	**D**
Specify Engine Size	**1.6**
Durability	**2-3 years**
Type of Vehicle	**luxury**
No. of Exhaust	**2**
Country of Origin	**UK**
Timeframe	**1**

Answer:

OUTPUT SUMMARY

Item	Cost (£)
Pipes	10
Front Muffler	0
Rear Muffler 1	9.5
Rear Muffler 2	0
E-Glass	1.1
Assembly Costs	5.7
Other Costs	11
Total Piece Cost	**37.3**

6.3.9. Validation of Results

As mentioned earlier in the chapter (section 6.3), the author organised a workshop to validate and get the comments of the experts with regards to the usefulness of the FUCE framework and the model created. Except the experts that participated in the development of the case study, two more cost estimators, one CE-E (with 5 years of experience) and one CE-C (with 2 years of experience) were invited to participate in a presentation of the methodology and to use the final model created.

The model was also validated with another automotive organisation. Two other cost estimators, one CE-C (7 years experience) and one CE-E (8 years experience) reviewed the model and agreed that although it did not provide very accurate results, as an indication for the cost was very good.

The areas of interest that the author asked the participants to comment on are presented below. Characteristic comments from the participants are presented, as captured by the author during the meeting, as qualitative evidence:

<u>Performance</u>

"I think that the methodology is straight forward to use. The only difficulty is when we try to create the relationships. The data needed for this is not always available at once. That means we have to have many meetings to arrive at the end"

"To get the data was not as difficult as it was time consuming. We do not know currently who has the information we need. I believe that if we decide to move this (approach) forward we will have to organise a system to save the data we need"

<u>Accuracy</u>

"I think the outputs of a model are as good as its inputs. The model was developed to provide cost estimates for the conceptual stage. I think the accuracy achieved for that is satisfactory"

<u>Ease to Use</u>

"The methodology was quite straight forward, the only difficulty for me was to try and think of the product in terms of the functions it fulfils. The engineers that took part helped me to identify what I wanted to say in terms of functions"

<u>Relevance</u>

"I don't think that is something we could use every day, as indeed we don't need to. But when we need to look at concepts or what-if scenarios, then definitely"

Completeness

"The detail achieved was good. We had to keep certain parameters in the model constant otherwise the model would be very complicated. For what we need it, its very good"

Integration with business

"I don't think that it will be difficult to implement this approach. It is quite straight forward. First we have to develop (FUCE) models for the commodities that are more difficult to calculate (cost) estimates. Then we need to connect with our other (database) systems in order to retrieve new rates automatically for the stored estimate (referring to the possibility of providing an automatic approach to updating the cost rates used in the model in future time)"

Transferability

"For hardware products I think we proved that it works. I am not sure though that it would work for electronics"

Interaction of CE-C and CE-E

"By following the framework and creating the exhaust muffler model, we have created in effect a translator in place between commercial (CE-C) and engineering (CE-E). By that I mean we have a system that manages to use a small amount of input information to provide a detailed estimate. CE-C can respond to requests by receiving a very small amount of information indeed. Now we can provide them an estimate for the muffler within a couple of minutes. Before it would take at least a couple of days as we had to go and find some more information about their request"

"I believe the great benefit of FUCE is not only the resultant model of the commodity that we analyse but the methodology and the way both groups (CE-C and CE-E) interact in order to develop that model. I cannot think of a circumstance that I spend so much time together with commercial people!"

Qualitative analysis of the validation results resulted in few changes in the framework and in the specific case study. The changes and a summary of the validation results are presented below

Commercial changes

One of the immediate changes to the model as was mentioned earlier was the incorporation of the Commercial inputs on the model, country of origin and timeframe. This enabled the CE-C to make better decision on the conceptual design stage and get immediate feedback on the cost implications depending on their choices.

Rates

Another point raised by the participants in the study was that some of the rates used were not current or realistic. The author had to create his own rates initially wherever a rate was not available. For example all the rates used for labour in countries like India and China is fictional. Nonetheless the impact on the overall estimate is realistic as it will reduce the labour cost compare to a European country like the UK.

Objective approach

CE-E were very satisfied with the conditions the model was taking under consideration for the creation of the cost estimate. One observation made by an engineer was that the model was creating an objective description of the product without taking into consideration personal preferences. Indeed in some cases the cost estimate produced by the model, had a value lower than the current solution implied by the organisation. Once asked why such a solution was implemented rather than the more cost effective one presented by the model, the answer was that historically the organisation was satisfying the functionality of the component with a certain philosophy of design. After the case study the organisation decided to look into the practices followed for their commodity and see where appropriate changes needed to be made.

All the participants in the validation said that an advantage of the model was that whenever there was a need for somebody to understand how the estimate was created, the assumptions made were documented within the model in terms of the tables and relationships created. Furthermore because they all participate in the development of the model a very good understanding of the product had been achieved by both CE-C and CE-E.

CE-C View

CE-C were happy with the creation of the model. Creating the model with CE-E allowed them to understand the reasoning and the assumptions behind the creation of the product and the cost estimate. They commented that once the Excel model was created they could use it autonomously in order to retrieve information. Furthermore, because all the details of actual rates used could be coded and be hidden from the user, the tool could be used outside the organisation in negotiations with suppliers.

CE-E View
CE-E had the ability to create their estimates together with the CE-E and in accordance with the standard processes they use, i.e. bottom up estimating. Once the model was created, they could provide answers to CE-C in a matter of minutes. This process before the model would otherwise take a couple of days.

Final Observations
- All the experts agreed that the framework is applicable to other mechanical parts of the vehicle;
- The cost estimate that was produced is company specific but the framework is generic with automotive industries;
- The framework once implemented will improve interaction between CE-C and CE-E and thus improve the internal practice of CE.

Finally, the automotive organisation of this case study decided to make improvements to the model by applying further expertise from its organisation, which was not available to the author and apply the framework to other commodities.

6.4. Summary

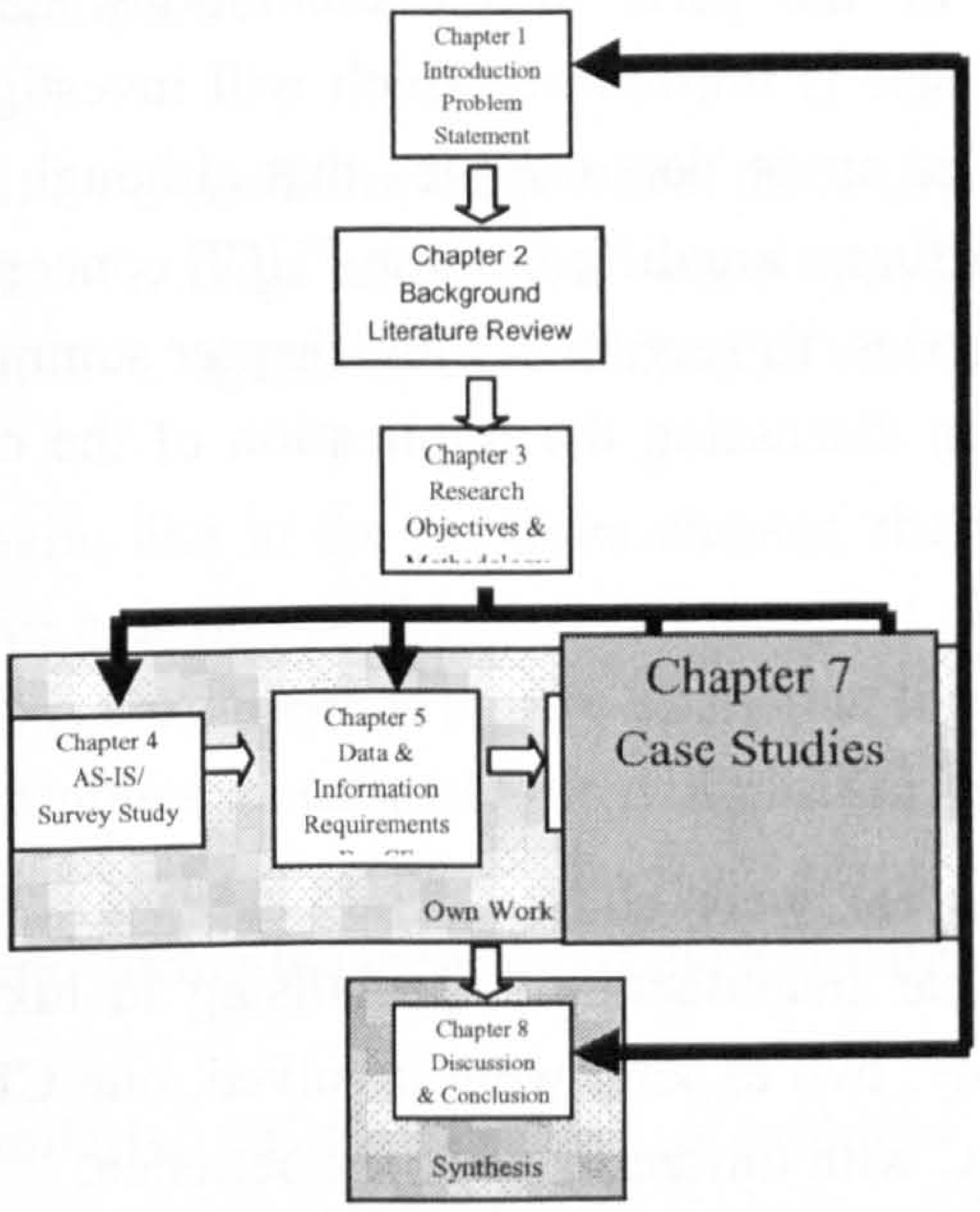
This chapter addresses the issue of interaction between commercial and engineering disciplines within cost estimating at the conceptual design stage. It introduced the concept of **'Function-based cost estimating'** (FUCE) as a linkage between commercial and engineering activities.

A methodology was presented that will allow cost estimators to base their estimates on the functional characteristics of their product. An example was presented based on the automotive industry. The model proved that it is possible to create estimates based on the specifications of the car and the functions of the product under investigation, thus integrating commercial and engineering knowledge within cost estimating. The author believes that this approach will help to improve communication between the disciplines involved in costing and assist estimators at conceptual design stage.

In the following chapter two more case studies are presented, one from automotive and one from aerospace industry. The methodology was introduced and followed by CE within their own environment and observations were made that will be analysed in the discussion of the thesis.

THIS PAGE IS INTENTIONALLY LEFT BLANK

7. Further Case Studies



In chapter 4 the author identified the need for a framework that will improve the communication between CE-C and CE-E in cost estimating at the conceptual design stage. His approach included developing a data infrastructure for cost estimating (chapter 5) and the function-based cost estimating methodology (chapter 6). Within this final stage of the research the author applies the framework in two other case studies, with significant differences between each other and compares them to the first case study developed in chapter 6. With this view in mind, the aim of this chapter is:

Chapter Aim:
To demonstrate that the framework can be applied to more that one case and to investigate its generality.

The first case study was developed with another automotive company. The objective was to prove the generality of the model, so that it can be applied to mechanical parts in industries (of high volume, low cost products) that use detailed bottom up estimating.

The second case study was developed with the collaboration of an aerospace manufacturer. The objective was to investigate how the FUCE framework will behave in an industry (of low volume, high cost products) were the cost estimating practices and cost estimating techniques are different than the rest of the mass production hardware industries.

Both studies have their own unique points; one product is a relatively small automotive part with quite big standardisation among its parts. The other is an aerospace product that is much more complicated to manufacture, and the cost estimating techniques and data associated to it are different than automotive.

Section 7.1 deals with the first case study, the FUCE methodology is followed and the model is created with noticeable changes compared to the earlier study, the main reason being the standardisation of the parts of the commodity under consideration. In section 7.2 the second case is introduced which will investigate the use of FUCE to another industry. The study demonstrates that although the techniques followed by aerospace manufacturers are different, the FUCE concept is widely accepted by experts from all industries. In section 7.3 the chapter summary and key observation are presented, before discussing the implication of the case studies and the entire thesis in chapter 8.

7.1. Case study 1-Sideshaft

For this case study the sideshafts of the car were chosen. The case study was developed with the assistance of a big car manufacturer, specialising in luxury vehicles. For the purpose of the case study, two experts were involved, one CE-E with six years of experience, and one CE-C with thirteen years of experience.

The first task for the case study was to familiarise the researcher with the commodity under investigation. The CE-E responsible for that commodity was interviewed and provided background information to the researcher. The case study was completed over a period of three months. The reason for the long period was the difficulty in acquiring the requested information (description of commodity and historical cost estimates) and managing to conduct the meetings with the participation of both parties due to their work commitments. Once the major data collection was performed the author continued developing the model with the expert for the specific commodity. A supplier of the commodity and an engineer from the product development team of the automotive company-with considerable experience of over 10 years each-were consulted for refining the model. After the completion, the model was presented to the group of experts for validation and suggestions. As in the case study in the previous chapter, the author asked the participants to comment on the following matters: performance, accuracy, easy to use, relevance, completeness, ease of adoption, transferability and integration of CE-E and CE-C.

Scenarios

The typical scenario tried to address in this case again relates to the internal interaction of CE-C and CE-E. At the development stage of a car, CE-C will require a cost target for the sideshaft component and they will ask a CE-E to provide an estimate *based on different vehicle specifications.* The types of questions they will have to answer, for example, are "How much will the sideshafts cost for a...:

i. ...medium, front-wheel drive (FWD) car"
ii. ...large luxury, rear-wheel (RWD) car?"
iii. ...sports utility vehicle (SUV) with all wheel drive (AWD)?"

Again, like in the previous chapter, the CE-E can produce an estimate when they have a design or the physical part, but when the available information is so vague this is a problem. It is very likely that if you get a CE-E with 20 years of experience to produce an estimate, he will provide a cost very different from an estimator with 5 years of experience. The main reason for that will be the different assumptions made during the creation of the estimate.

Similarly, CE-C will have a problem as we referred in the previous chapter. Commercial people do not understand how the specifications affect the product under investigation and why the costs change. The objective of this study will be to develop a cost estimating model that will have to provide answers to questions i, ii, and iii. Before the methodology is followed, a description is provided for the sideshafts.

Sideshaft

A sideshaft is found in every automotive vehicle. It usually comprises of two universal joints and an interconnecting shaft. As mentioned in previous chapters, in cases like these the CE-E are not able to provide a cost estimate at conceptual design stage because the information available to them is very abstract. Any attempt to provide an estimate is based on the assumptions and rationale of an individual cost estimator. The information available at this stage comprises of functions and requirements the vehicle needs to perform. The FUCE framework will try and associate these requirements with the cost model. In the next sections a brief description of the product under consideration will be presented.

Universal Joint

A Universal Joint is an apparatus for transmitting torque between two shafts which lie at an angle to one another, as shown schematically in figure 7-1.

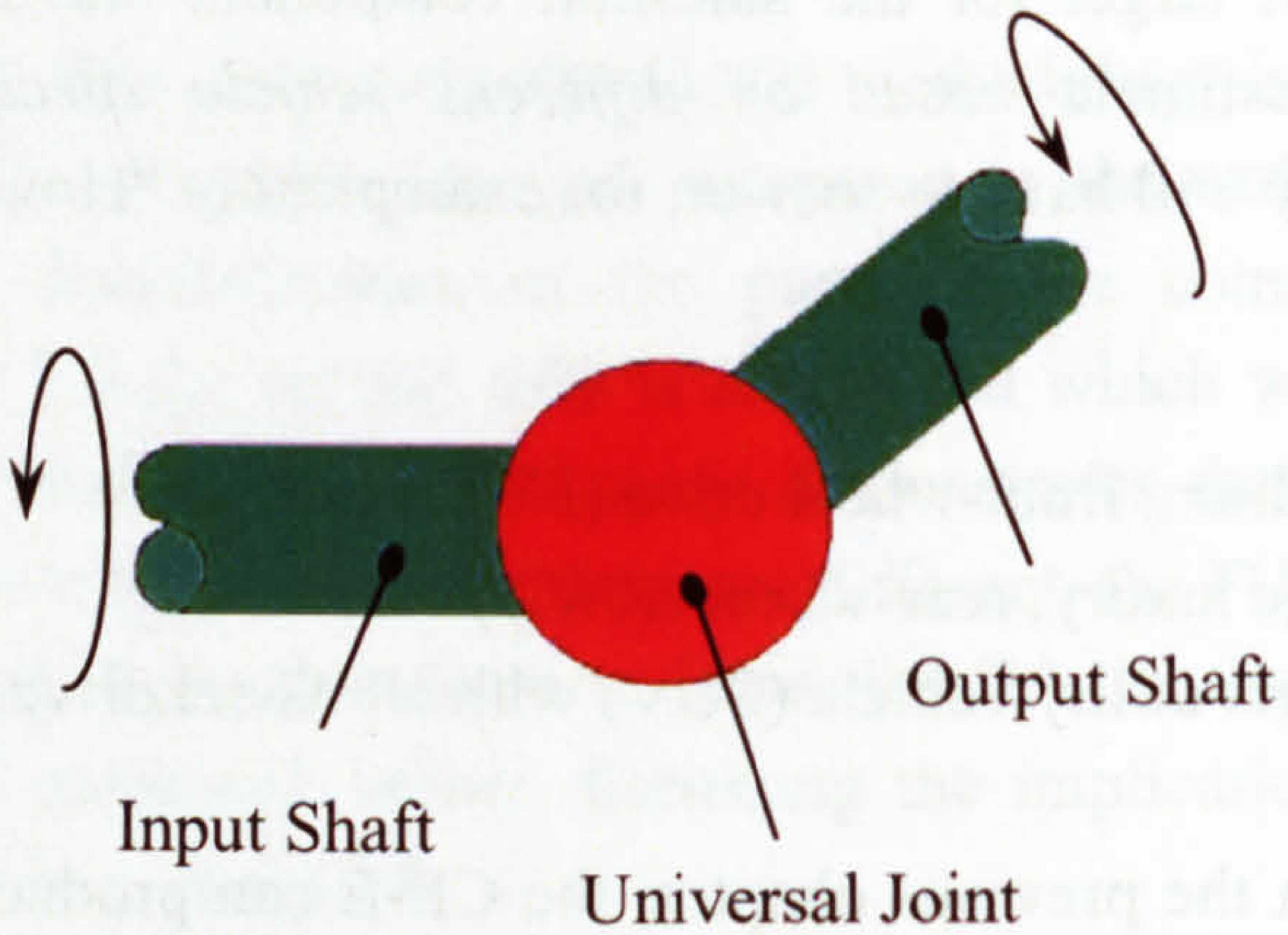


Figure 7-1: The Universal Joint

There are many applications for such a mechanism, but probably the most common is found in the automotive industry as a means of transmitting drive. This is illustrated in figure 7-2 which shows a four wheel drive vehicle. The front sideshafts are shown in yellow, each having two universal joints, one by the front differential and one by the wheel. These accommodate the various angles through which the drive must pass as the wheels turn to steer the vehicle and as the wheels move up and down on the suspension. A propshaft, shown in green, transmits drive to the rear differential and has a number of universal joints which accommodate the movements of the differential as it rises and falls on its suspension. Finally, the rear sideshafts, shown in red, transmit drive to the rear wheels and each has two universal joints, again, to accommodate suspension movement.

Plunging Universal Joint

A 'plunging' or 'axially free' universal joint is capable of transmitting drive through two shafts inclined at an angle to one another and simultaneously allowing axial movement along one of the shaft axes. This is illustrated in figure 7-3.

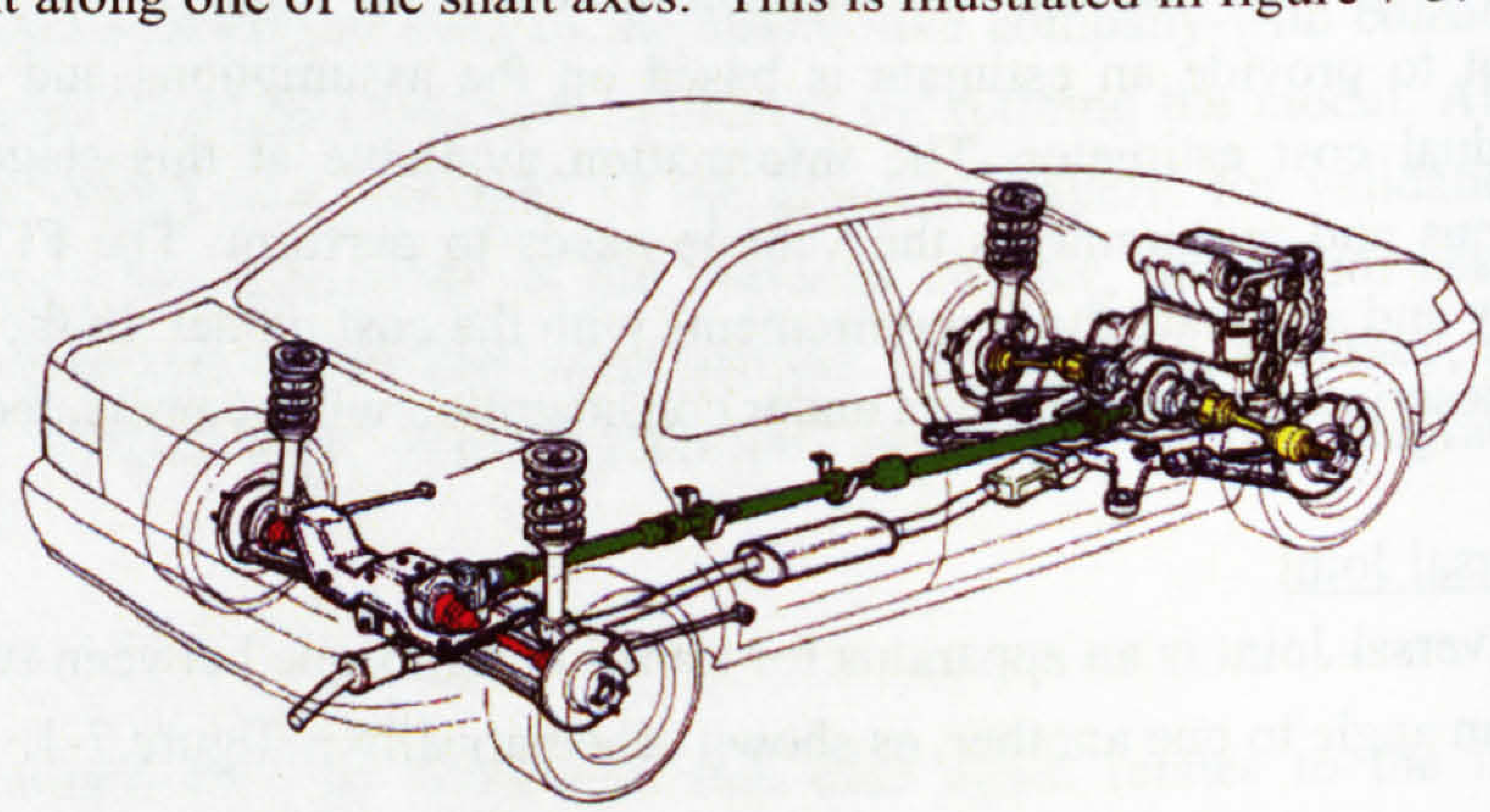


Figure 7-2: Use of Universal Joints in Automotive Drive Lines

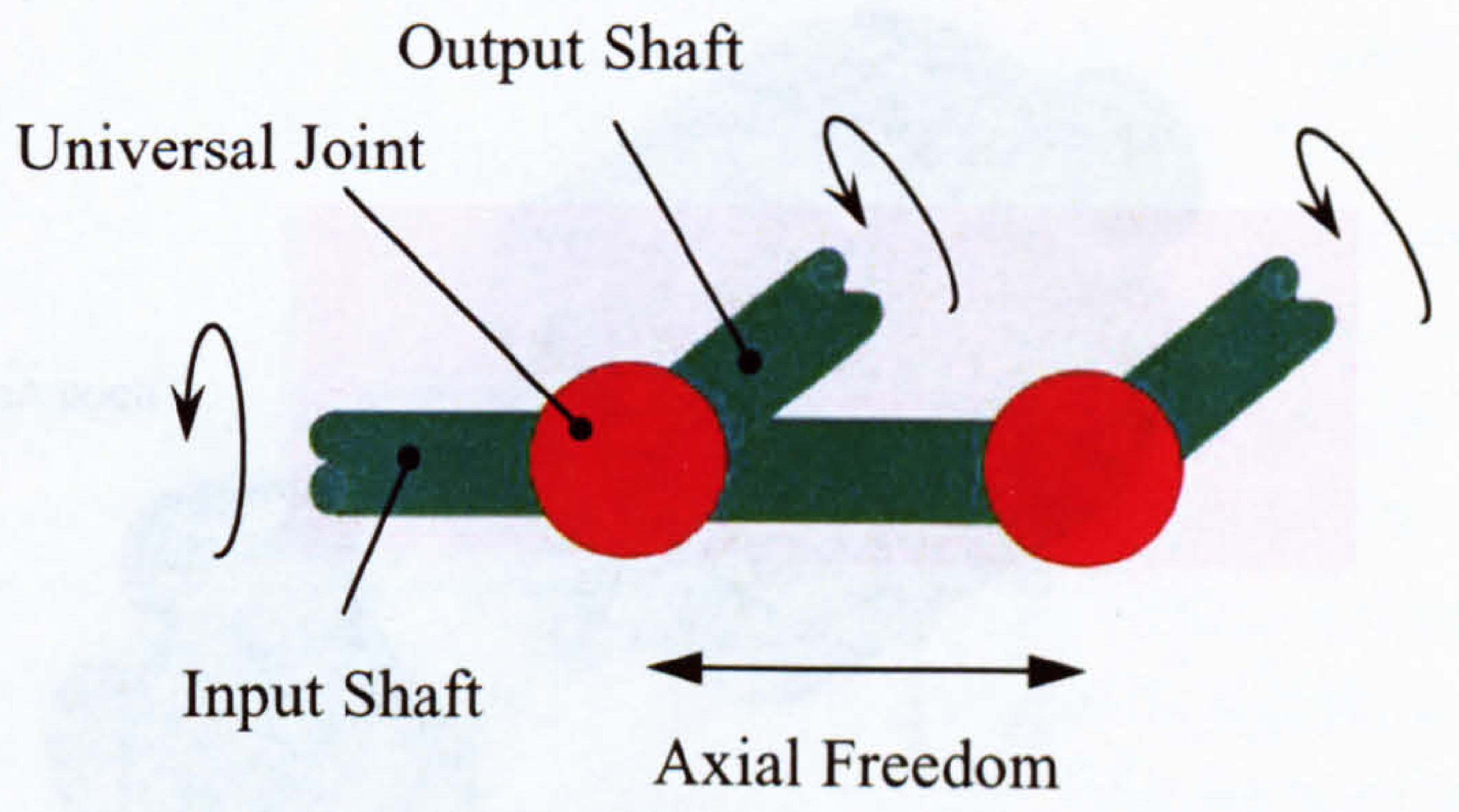


Figure 7-3: Axially Free Universal Joint

G.I. Joint

The 'G.I.' or 'Glaenzer Intérieur' joint was developed by the French company, Glaenzer Spicer, as an axially free inboard constant velocity joint for front wheel drive vehicles. Originally, it was used in conjunction with the 'G.E.' or 'Glaenzer Extérieur' joint, an axially fixed constant velocity joint, as illustrated in figure 7-4. Both the G.I. and the G.E. joints use rollers rather than balls to transmit the drive.

The G.I. joint is a 'tripod joint', having three 'feet' or 'pods', and is illustrated in figure 7-5, 7-6, and 7-7. The torque is transmitted from the outer race to the connecting shaft by means of rollers running on needle rollers around the trunnions of the tripod spider. The roller tracks of the outer race enable the tripod assembly to move angularly and axially within the joint.

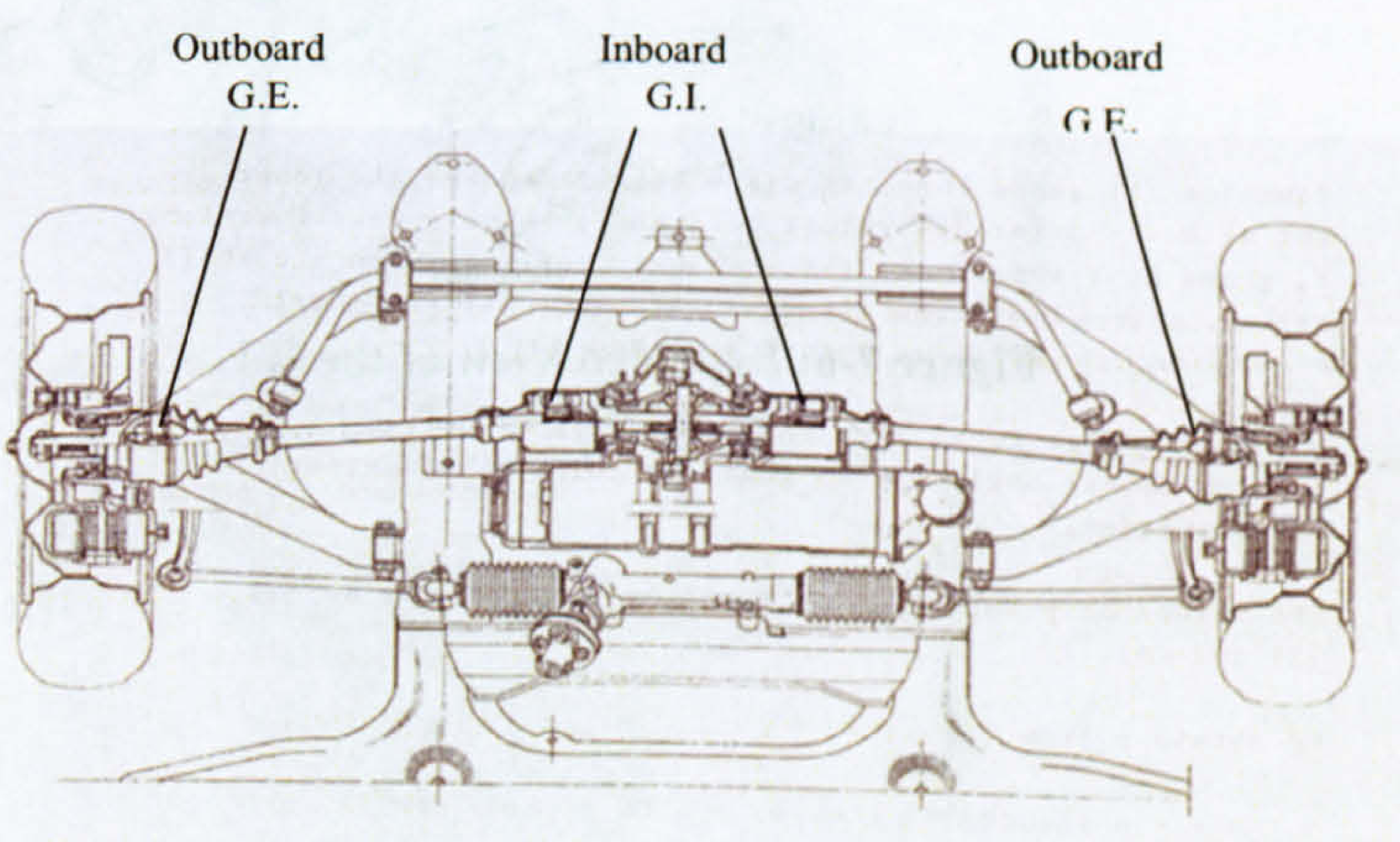


Figure 7-4: G.E. /G.I. Sideshafts

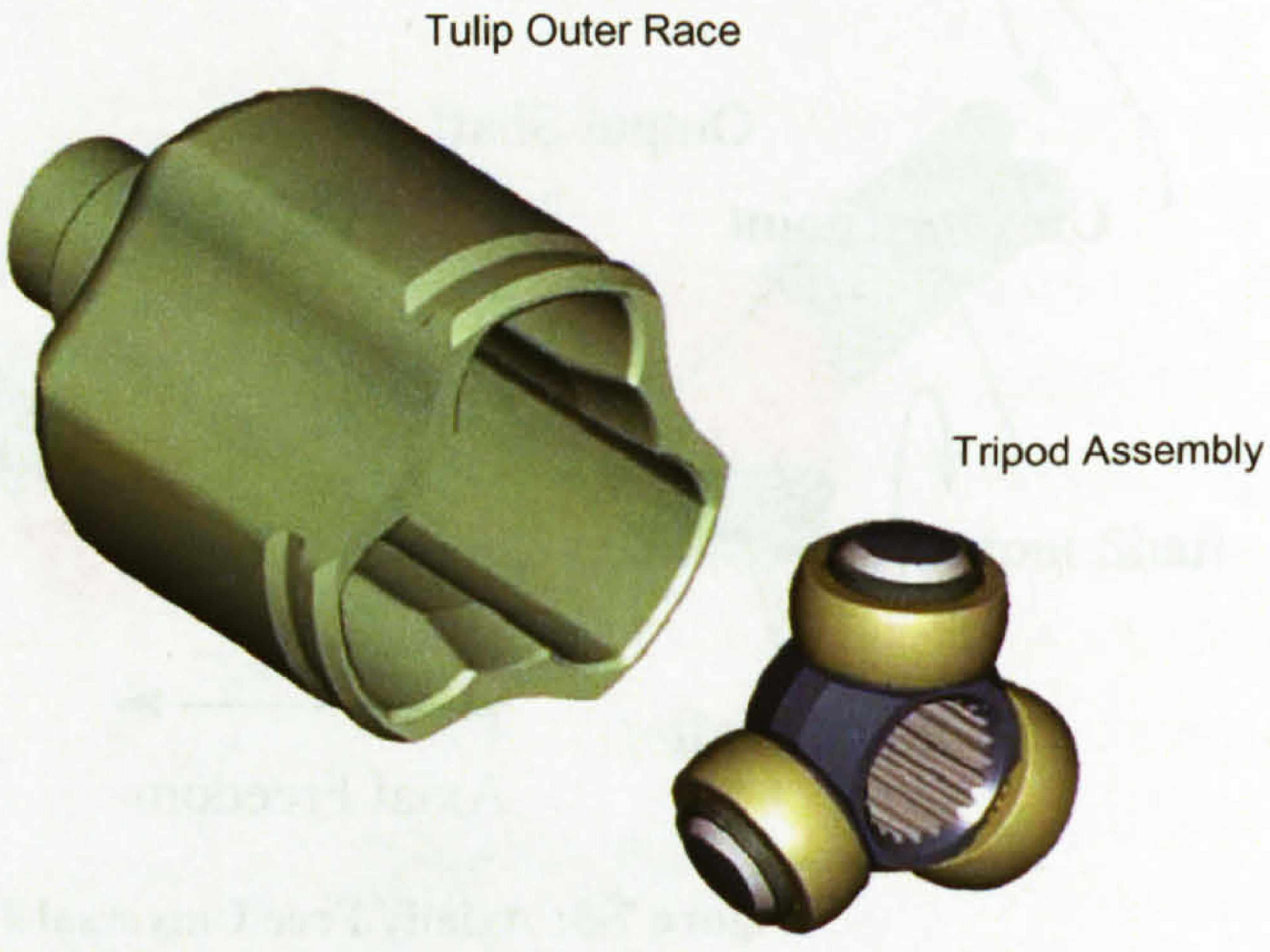


Figure 7-5: Tulip and Tripod

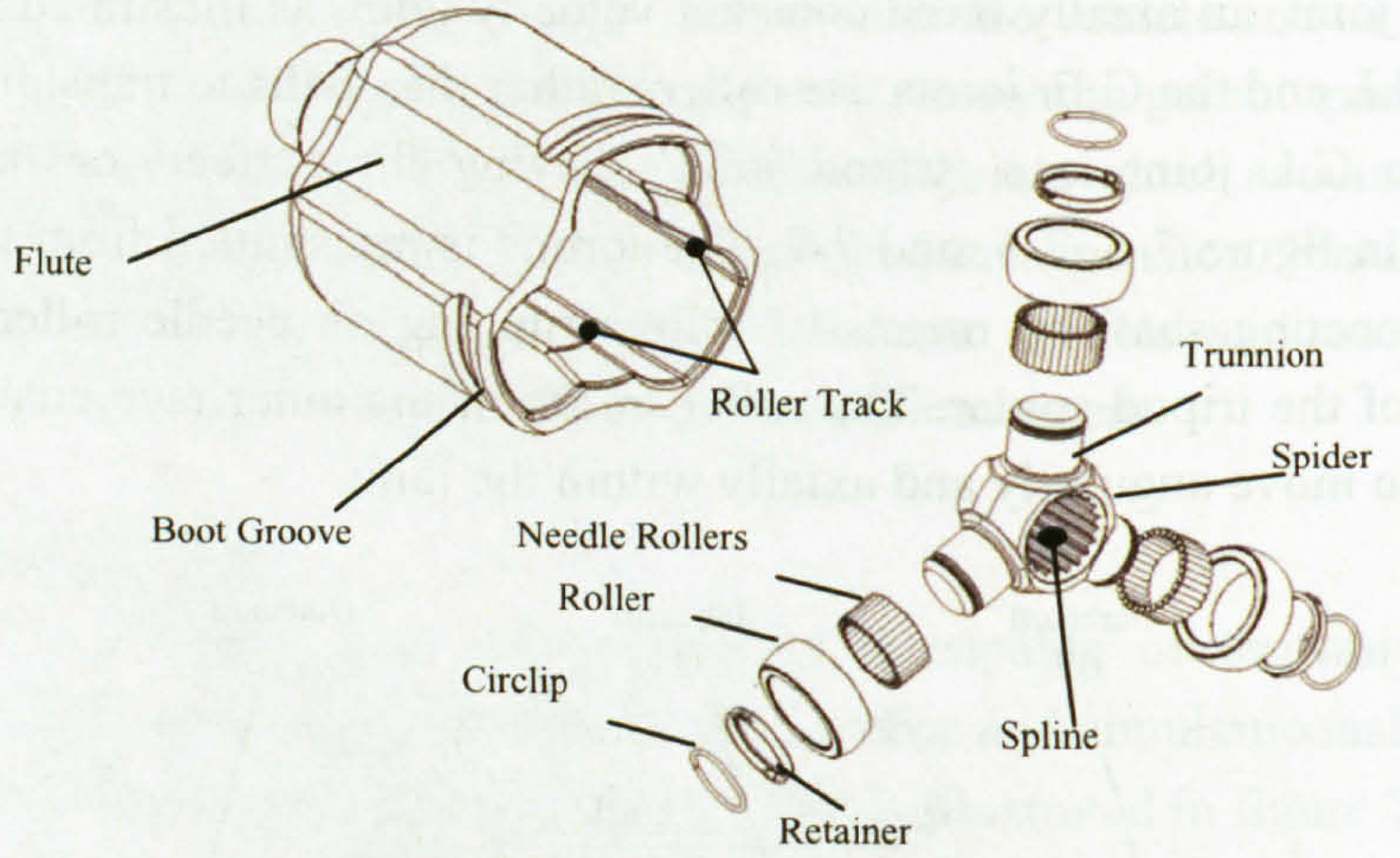


Figure 7-6: Exploded View of the G.I

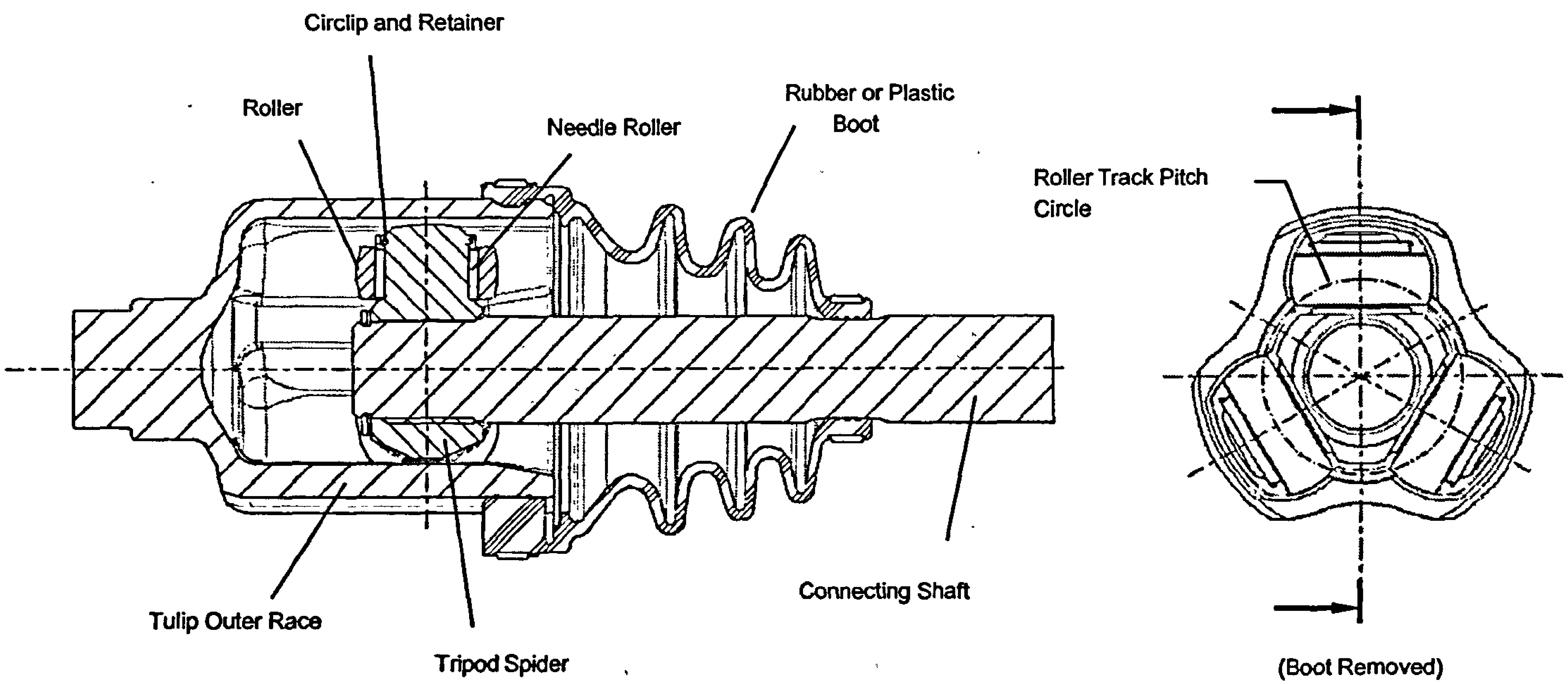


Figure 7-7: The G.I. Joint

7.1.1. Standardisation of Parts

An interesting observation during the data collection process was the standardisation of this particular part as a result of mass production. In conjunction with the specialised suppliers that can provide it, there was no big choice of options with regards to designs. Indeed as described earlier in the chapter there is a finite number of different joint that can be used. Appendix E1 demonstrates the different joints available from one supplier. The diagram presents the two different types available for the outboard joint (O/B) and the four types for the inboard joints (I/B). Each type of joint is characterised by the amount of torque that it can withstand and by the number of degrees through which it can operate. Due to the limited number of solutions then, it was possible to create an estimate for the entire range of joints. If the FUCE framework can relate to the solutions presented in this sheet, then the construction of the cost estimate will become simpler.

7.2. Applying the FUCE Methodology

7.2.1. Define Product Decomposition

Figure 7-8 describes the PD of the sideshaft. It was completed with assistance from CE-E and previous cost estimates created. Since one of the main reasons for performing the decomposition is to create the estimate, if estimates for the same commodity are available, the task of compiling the study becomes easier. In this case-study estimates were available; indeed this was one of the reasons that the specific commodity was selected. The PD forms the basis for creating the detailed cost estimating model. A detailed estimate for the sideshaft can be found in Appendix E2.

Although the PD could have been developed in greater detail, it was agreed by all the participants that this high level approach was much more efficient for the purpose.

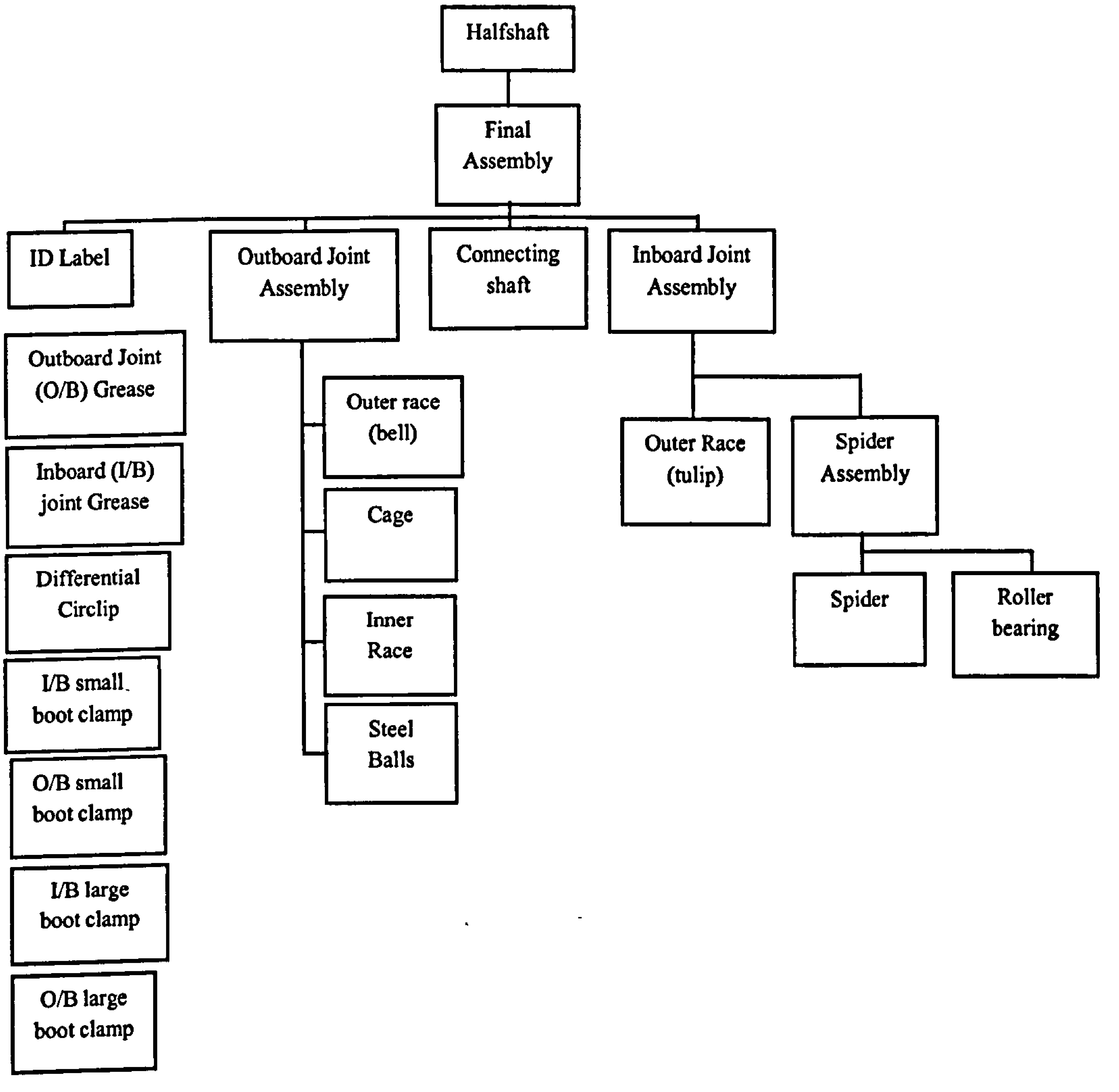


Figure 7-8: PD of sideshaft

A snapshot of the detailed estimate can be found on the next page (figure7-9) where the cost estimate of the 'outboard joint forging' and 'outboard joint machining' is presented.

As mentioned earlier in the chapter, due to the big standardisation of the specific commodity, there were a finite number of solutions that could be used in a car. As a result the amount of different cost estimates was restricted to the different types of joint available (ACi, UF, UFi, AAR, etc., see appendix E1). For example, different cost estimates needed to be created for the elements in figure 7-9. On the other hand other parts were kept the same during all the estimates like the connecting shaft (figure 7-10).

Description	Mat Usag	Mat Rate	Man Level	LB G	Lab Mins	Lab Ra	Mat Cos	Lab C	Item Cost	Manuf C	Comp	Man. Cost
OUTBOARD JOINT FORGING - I												
Part Number: 1X43-3B437-AD												
817M40IM 820H17 / 40NICRMO6	1.343	0.577					0.852		0.852	0.852	GBP	0.852
BILLET SHEAR MAX BAR DIA: 125 MM			0.5	AB	0.016	0.3		0.01	0.015	0.015	GBP	0.015
INDUCTION BAR HEATER MAX BAR I			0.5	AB	0.056	0.3		0.02	0.123	0.123	GBP	0.123
4 STATION 1600 TONNE WARM FORG			3	CB	0.4	0.29		0.12	0.772	0.772	GBP	0.772
PHOSPHATE COAT			1	AB	0.123	0.3		0.04	0.149	0.149	GBP	0.149
COLD FORM			1	CB	0.15	0.29		0.04	0.11	0.11	GBP	0.11
INSPECTION & PACK			1	AB	0.092	0.3		0.03	0.029	0.029	GBP	0.029
SUB					0.838		0.852	0.24	2.049	2.049	GBP	2.049
OUTBOARD JOINT MACHINING												
Part Number: A-026J-21323												
TURN COMPLETE - 2 AXIS CNC LATH			1	AB	1.875	0.3		0.56	0.809	0.809	GBP	0.809
CONVEYOR 7.6M X 2.2M				AB	0.625	0.11		0.07	0.095	0.095	GBP	0.095
MILL SLOT/DRILL - VMC				AB	0	0.3		0	0.094	0.094	GBP	0.094
ROLL SPLINE & THREAD				AB	0	0.3		0	0.108	0.108	GBP	0.108
INDUCTION HARDENING (AXLE SHAF				AB	0	0.3		0	0.157	0.157	GBP	0.157
CONVEYOR 7.6M X 2.2M				AB	0.625	0.11		0.07	0.095	0.095	GBP	0.095
ROLL MARKING				AB	0	0.3		0	0.01	0.01	GBP	0.01
TEMPERING FURNACE 1219 MM WID				AB	0	0.3		0	0.358	0.358	GBP	0.358
CONVEYOR 7.6M X 2.2M				AB	0.625	0.11		0.07	0.095	0.095	GBP	0.095
EDDY CURRENT TEST & SPLINE CHEC				AA	0	0.25		0	0.047	0.047	GBP	0.047
HARD TURN - 4 AXIS CNC LATHE			1	AB	0.625	0.3		0.19	0.325	0.325	GBP	0.325
2 SPINDLE CNC VERTICAL TURNING (			1	AB	0.625	0.3		0.19	0.509	0.509	GBP	0.509
MAGNAFLUX INSPECTION			2	AB	0.625	0.3		0.19	0.209	0.209	GBP	0.209
SUB					5.625		0	1.31	2.913	2.913	GBP	2.913

Figure 7-9: Snapshot of outboard (O/B) Joint

Description	Mat Usag	Mat Rate	Man Level	LB G	Lab Mins	Lab Ra	Mat Cos	Lab C	Item Cost	Manuf C	Comp	Man. Cost
CONNECTING SHAFT												
Part Number: A-02629-119												
BAR STEEL CARBON	1.573	0.6226					1.077		1.077	1.077	GBP	1.077
FACE & CENTRE			1	AB	0.667	0.3		0.2	0.247	0.247	GBP	0.247
CONVEYOR 7.6M X 2.2M				AB	0.667	0.11		0.07	0.102	0.102	GBP	0.102
FINISH TURN BOTH ENDS				AB	0	0.3		0	0.259	0.259	GBP	0.259
AUTO GAUGING STATION				AB	0	0.3		0	0.035	0.035	GBP	0.035
ROLL SPLINE				AB	0	0.3		0	0.206	0.206	GBP	0.206
ROBOT-6 AXIS 12KG MX P/LD				AB	0.667	0.11		0.07	0.115	0.115	GBP	0.115
ROLL SPLINE				AB	0	0.3		0	0.206	0.206	GBP	0.206
CONVEYOR 7.6M X 2.2M				AB	0.667	0.11		0.07	0.102	0.102	GBP	0.102
INDUCTION HARDEN			1	AB	0.667	0.3		0.2	0.366	0.366	GBP	0.366
STRAIGHTEN & CRACK TEST - 2 MAC			0.5	AB	0.111	0.3		0.03	0.049	0.049	GBP	0.049
SUB					3.444		1.077	0.64	2.765	2.765	GBP	2.765

Figure 7-10: Snapshot estimate of connecting shaft

Due to the complexity of the estimate, a simpler version is used to demonstrate the case study (figure 7-11).

Item	Cost (£)
Connecting Shaft	
I/B Joint	
O/B Joint	
Assembly Costs	
Total Cost	

Figure 7-11: Summary of Sideshaft Estimate

7.2.2. Define Functional Decomposition

The next step in the methodology was to define the FD. By applying the FAST technique, the diagram in figure 7-12 was developed. The entire team participated in the FD. The main function of the driveshaft is to transmit the torque from the engine, a description of the driveshaft was provided earlier in section 7.1.

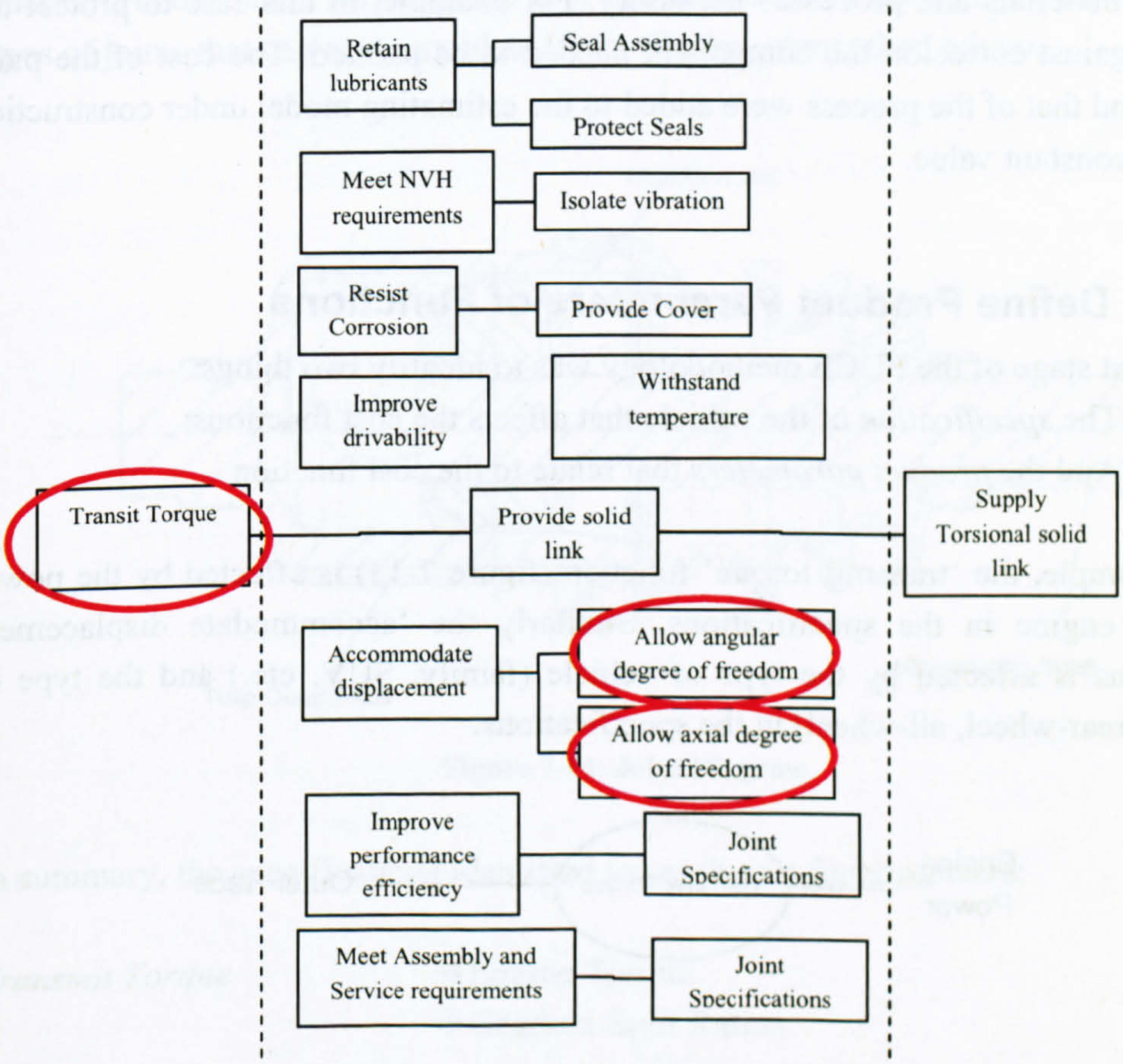


Figure 7-12: Functional Decomposition of sideshaft

7.2.3. Identify Cost Functions

The team needed to select the functions that were going to be used for the later stages of the FUCE framework. The importance of the functions and the associated cost related to that function, as the experts could predict through their experience played a major part. The functions identified were:

1. Transmit Torque
2. Allow Angular Displacement
3. Allow Axial Displacement

The rest of the functions, for example, *resist corrosion, improve performance efficiency,* etc. were considered to be necessary regardless of the product solution achieved in the end, and therefore needed to be included in the cost estimate as a *constant* value. This meant for, for example, in the cases of the *resist corrosion* function that all the costs necessary to achieve it will have a constant value based on the materials and processes necessary. For example, in this case to protect the shaft against corrosion the component needed to be painted. The cost of the paint itself and that of the process were added to the estimating model under construction with a constant value.

7.2.4. Define Product Parameters of Functions

The next stage of the FUCE methodology was to identify two things:

- The *specification* of the vehicle that affects the cost functions;
- And the *product parameters* that relate to the cost function

For example, the 'transmit torque' function (figure 7-13) is affected by the power of the engine in the specifications. Similarly the 'accommodate displacement functions is affected by the type of vehicle (family, SUV, etc.) and the type of Drive (rear-wheel, all-wheel) in the specifications.

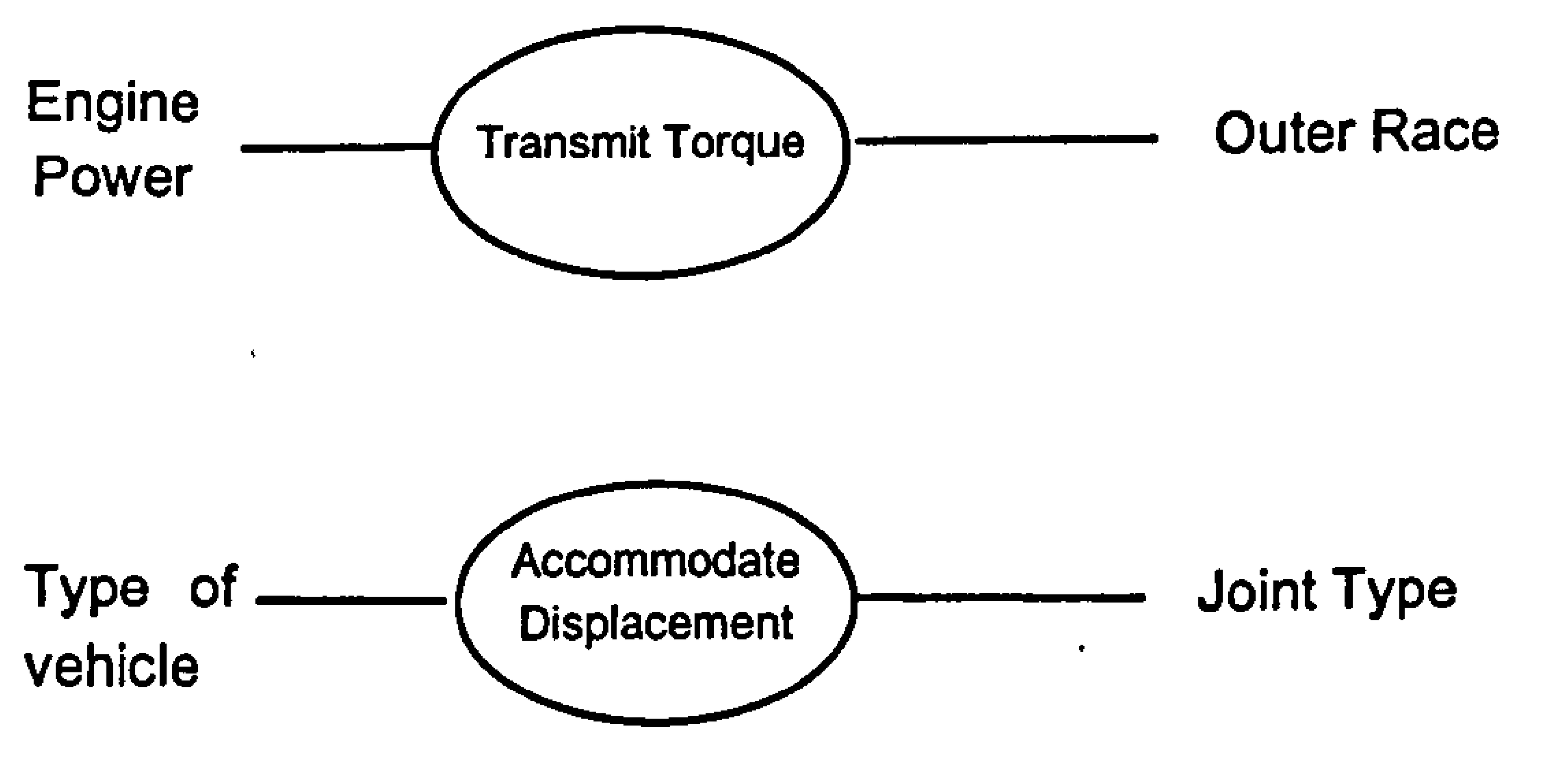


Figure 7-13: Function Relationships

To identify those parameters, the help of the product development engineer was the most significant as he possessed the best understanding. The engineer knew very well how these functions are affected and what were the parameters involved. To *transmit torque* the joint size (outer race diameter) was the single most important attribute (figure 7-14). The other elements associated with the joint, like bearings, needle rollers, etc. was considered to be similar to be included in the model. Instead they were included as a constant cost element in the estimate.

The angular and axial displacements were grouped under a single *accommodate displacements* function. The joint type was the physical attribute that affected the function. As described earlier in the first sections of this chapter, there are different types of joints that can accommodate larger displacements than others.

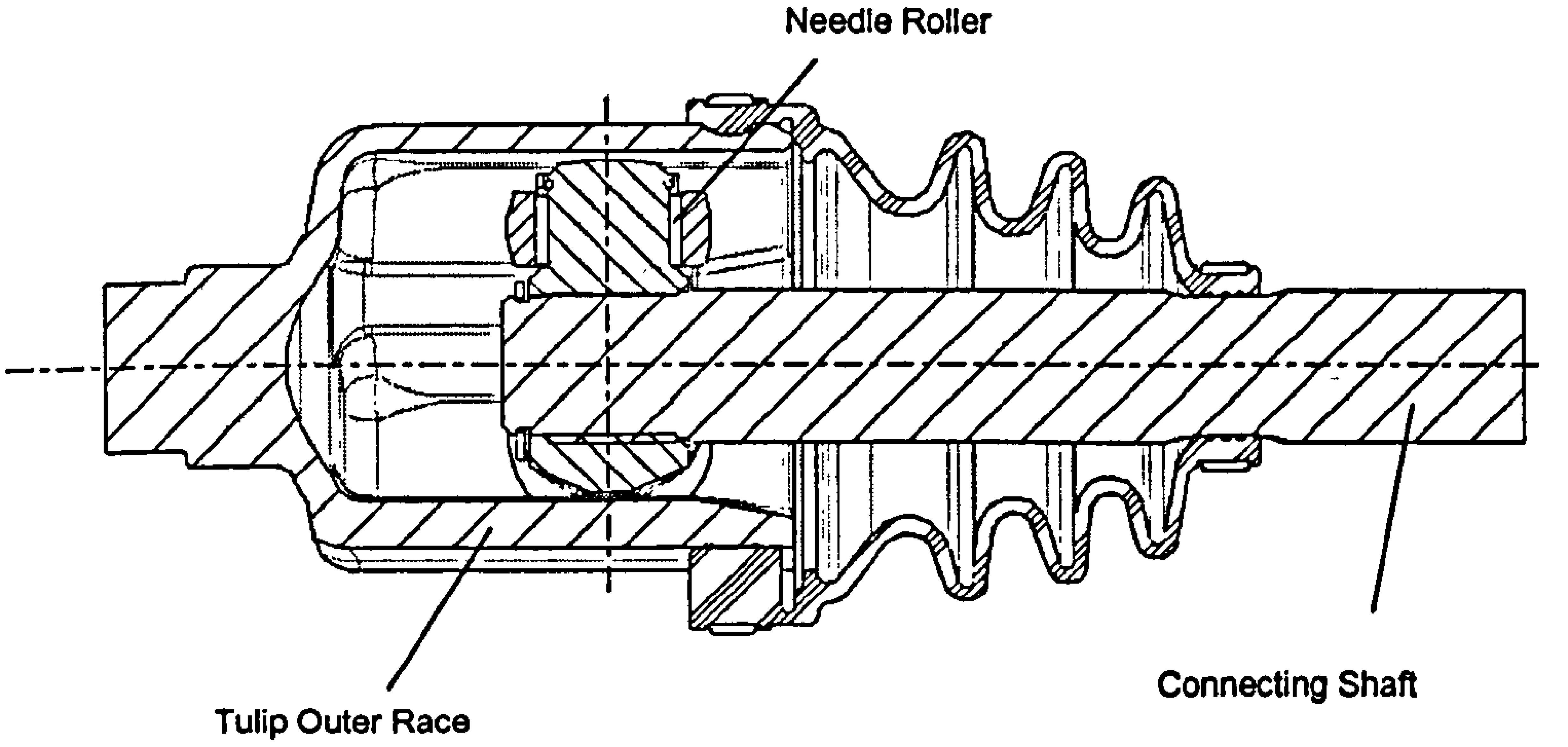


Figure 7-14: Joint Diagram

In summary, the specifications identified for each cost function were:

Transmit Torque	→Engine Torque →Gearbox Split Ratios
Accommodate Displacement	→Drive System →Car Type

These specifications would form the *input* to the Excel model that would be created.

7.2.5. Create relationships between functions and product parameters

From Figure 7-13 the physical parameters that were identified were the *joint type* and the *outer race*.

Joint Type

Table 7-1 represents the relationships between the Joint Type attribute and the parameters associated with it that was created with the experts. By selecting a *type of vehicle* (normal car/sport utility vehicle SUV) and the *drive system* (Forward wheel drive (FWD), rear wheel drive (RWD), all-wheel drive (AWD)) the joint type can be specified. (Please note that the types of joints AC, GI, etc. are related to the tables in appendix E1).

For example if there was a request for an AWD, SUV car, the selections are presented in table 7-2 in the greyed areas.

Table 7-1: Relational table representing all possible solutions for joint type

	FWD		RWD	AWD		
	Normal	SUV	Normal / SUV	Front		Rear
O/B	47^o AC	50^o $UF_{(i)}$	47^0 AC	50^o UF		47^o AC
I/B	Normal $GI_{(i)}$	SUV $AAR_{(i)}$	GI	Normal GI	SUV AAR	 DO_i

Table 7-2: Selection for an all-wheel drive, SUV car

	FWD		RWD	AWD		
	Normal	SUV	Normal / SUV	Front		Rear
O/B	47^o AC	50^o $UF_{(i)}$	47^0 AC	50^o UF		47^o AC
I/B	Normal $GI_{(i)}$	SUV $AAR_{(i)}$	GI	Normal GI	SUV AAR	 DO_i

The front outboard joint would be a UF and the rear an AC. The inboard joint would be in the front an AAR type and in the rear a DO type (see appendix E1 for specifications).

For example, in table 7-3 the user will need to select one of the UF joints. In order to be able to specify which one, the outer race diameter will need to be specified which is explained in the next paragraph.

Table 7-3: Selection of UF joint form list of joints

FIXED BALL JOITN TYPE **UF**		
Joint size	Outer race diameter (mm)	Nominal torque (Nm)
UF 1750	78	1750
UF 2500	88	2500
UF 3400	98	3400

Outer Race

In order to be able to select the size of joint, a relationship was created. This was developed by the experts based on a mathematical equation:

$$\text{Maximum Engine Torque x Split Ratio x F=Joint Size} \qquad (7.1)$$

Where:

- Maximum Engine Torque represents the torque produced by the engine;
- Split Ratio= (1st Gear ratio x Final Gear Ratio)/2. Split Ratios are easily acquired within an automotive manufacturer for different cars; The experts agreed that for an **SUV is 0.7** and for a **Normal car 0.4**
- F= 1 if gearbox is automatic
- F= 2 if gearbox is manual.
- Joint Size is relates to the tables in appendix E1

Value F in the case study was assumed as a *constant*. The experts agreed that for this case study an assumption needed to be made that all the cars would be manual. When the model is implemented in the company, values for both manual and automatic cars will need to be assigned.

So in this case if the selection for the SUV, AWD example had an engine that produced a torque of 150Nm then equation (7.1) would be equal 150x0.7x2=**210Nm**. Therefore a selection would be made from the table in table 7-4. Of course any selection of a bigger joint would also be able to be used, but for cost reasons the assumption is made that the selection needs to be the cheapest one that satisfies the requirements.

Table 7-4: Selection of UF joint

FIXED BALL JOINT TYPE **UF**		
Joint size	Outer race diameter (mm)	Nominal torque (Nm)
UF 1750	78	1750
UF 2500	**88**	**2500**
UF 3400	98	3400

7.2.6. Apply relationships to cost estimates.

In the previous section, the identification of the joint was made and was the *UF2500*. The Excel model created will substitute the cost of the UF in the overall estimate of the commodity. As a result the estimate will reflect the costs for the selection of specification made earlier, in this case the SUV, all-wheel drive car.

In section 7.2.4 the inputs of the model and the functions were identified. In section 7.2.5 the relationships were presented and an example of how they are implemented was provided. According to the introduction of this case study then inputs specified for the model are presented in figure 7-15.

After the analysis of the cost functions, the *Torque* was identified as an input to the model; therefore all the questions identified earlier had to be rephrased to include that input. The questions took the following form:

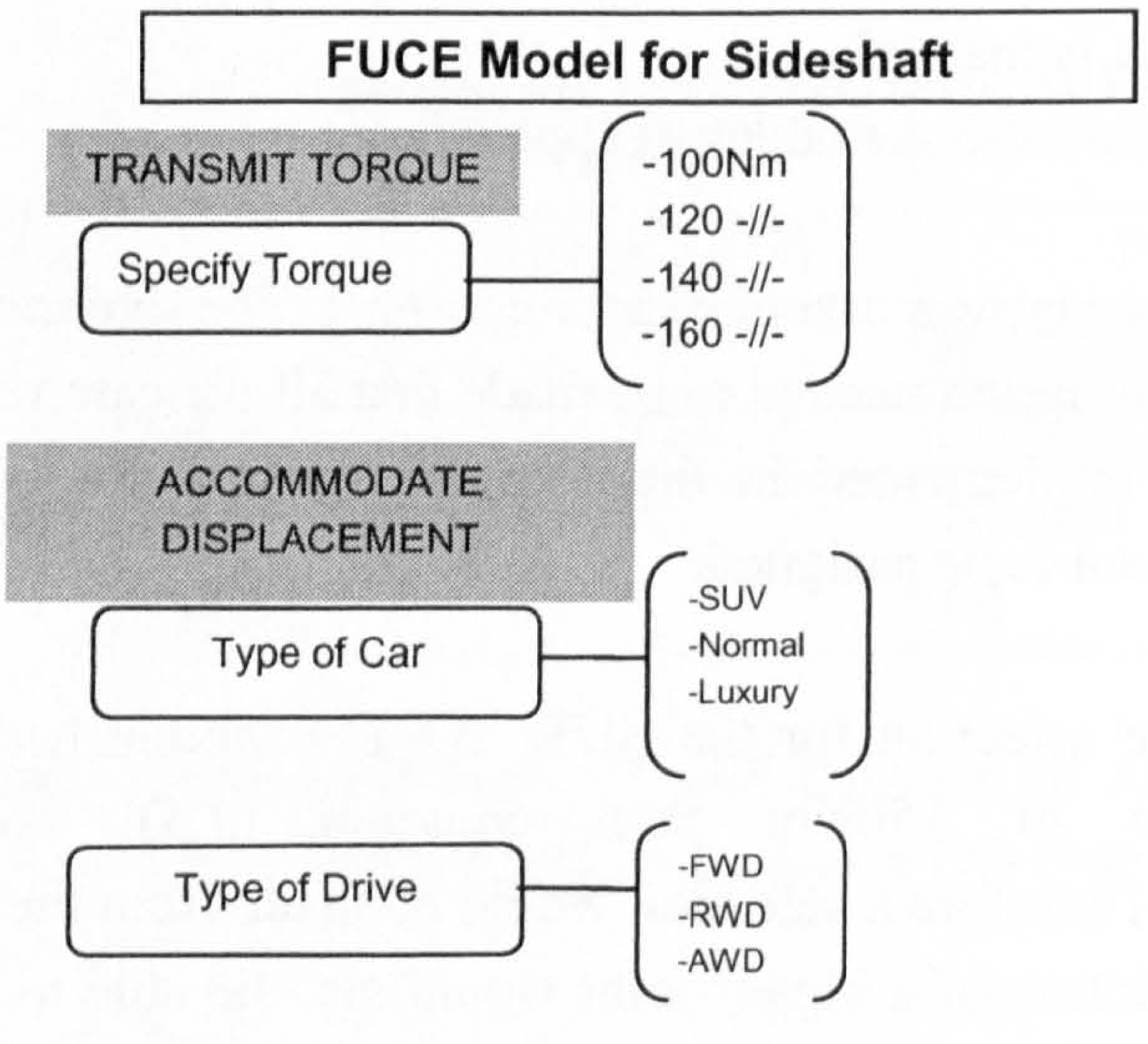


Figure 7-15: The available FUCE Inputs for the sideshaft model

The types of questions expert need to answer are, for example, "How much will the sideshafts cost for a…:

i)….medium, front-wheel drive (FWD) car, with a 150Nm torque?"

INPUT

Specify Torque	**150**
Type of Car	**Normal**
Type of Drive	**FWD**

Case i

Item	Cost (£)
Connecting Shaft	2.8
I/B Joint	11.2
O/B Joint	10.2
Assembly Costs	7.5
Total Cost	**31.7**

ii)….large luxury, rear-wheel (RWD) car with 240Nm torque?"

INPUT

Specify Torque	**240**
Type of Car	**Luxury**
Type of Drive	**RWD**

Case ii

Item	Cost (£)
Connecting Shaft	2.8
I/B Joint	11.2
O/B Joint	12.7
Assembly Costs	7.5
Total Cost	**34.2**

iii)...sports utility vehicle (SUV) with all wheel drive (AWD) and 310Nm torque?"

INPUT

Specify Torque	**310**
Type of Car	**SUV**
Type of Drive	**AWD**

Case iii

Item	Cost (£)
Connecting Shaft	2.8
I/B Joint	13.2
O/B Joint	14.75
Assembly Costs	7.5
Total Cost	**38.25**

By using the relationships defined earlier, the author can arrive at a solution with regards to the joint selection. By replacing the cost estimates of each joint to the estimate created in appendix E2, the estimators can predict at conceptual design stage the cost of the sideshaft. Other typical scenarios that might be requested are:

- "How much will it cost to transmit torque from a 4x4 vehicle with an engine producing 450Nm torque?"
- "Is there going to be an increase in the cost of the sideshafts if a bigger engine is introduced?"
- "Could we reduce the cost of the sideshafts if the engine size is reduced?"
- We plan to build a two-wheel, front drive vehicle that needs to accommodate for high displacements, how much will the sideshaft cost?"

7.2.7. Validation

As mentioned earlier, each step of the methodology was validated by all the experts. The model was presented to the experts, CE-C created different scenarios and CE-E validated the relationships and the cost estimate used. There was one change from the initial request we received. As the model was developed, it was apparent that there was a need to specify the torque of the engine, as indeed we applied in the model. It was later agreed between CE-C and CE-E that it would also be acceptable under certain circumstances to replace the torque requirements with the size of the engine as an input. Although this might not be the best way, it was much easier for the CE-C to come up with an engine size at the specification level. Assumptions would have to be documented with regards to engine sizes and output torque.

In general all the experts of the team were satisfied with the model that was developed. The participants not only enjoyed the model developed as an output, but also the methodology they had to follow as it allowed them to get a deeper understanding of the sideshaft. An interesting observation from a less experienced cost estimator, who was involved in a different commodity, was that now he was able to create an estimate for the sideshaft too although it was not his commodity. The same was true for the CE-C who could derive a result in minutes.

The areas of interest that the author asked the participants to comment on are presented below. Characteristic comments from the participants are presented, as captured by the author during the meeting, as qualitative evidence. In many cases there were very close similarities to the responses received in this case study with the previous case study in chapter 6. In these cases the author left comments out so that there are no repetitions:

<u>Accuracy</u>

"The cost estimate produced was much more accurate that I thought it would be. Mind you, I think this was because this commodity (sideshaft) has less parts compared to other ones. Also the fact that we based the estimates on known parts played a major fact"

<u>Ease to Use</u>

"I found it difficult to use the method. Maybe the fact that I am not an engineer played a major role. I think that I will need to work on a few more products before I get the hang of it"

<u>Interaction of CE-C and CE-E</u>

"It will definitely help me to create estimates for commercial people. More than that I don't see a problem giving them the model and create them themselves! As long as they cannot change the relationships or the rates, then I am sure they could get the same results by themselves"

<u>Summary of Observations</u>

- Both the experts involved in the case study agreed that the FUCE framework offered a systematic approach in matching the specifications requirements for the car with the requirements of the sideshaft. As a result a cost estimate was produced that was agreed by both commercial and engineering parties.

- Because the methodology involved both groups of CE, the experts commented in a positive way about the 'knowledge exchange' that occurred during those meetings between the two groups.
- All the participants agreed that the model could be applied in other hardware automotive parts.

7.3. Case Study 2-Vertical Tail Plane

It has been established that the FUCE framework can be implemented in the automotive industry as demonstrated in the two previous case studies. The author assumes that any other (hardware) industry that uses bottom up costing practices should be able to utilise the framework.

The motivation for this case study was for the researcher to see if the FUCE framework could be associated with the practices of the aerospace industry where the cost estimating practices are mainly focused on parametric models. Any differences that occurred compared to the two previous cases are highlighted in this chapter and discussed in the next one.

This case study was developed with the assistance of a large aircraft manufacturer. A group of three people were involved, each one of them having experience of more than 20 years. One was a CE-C, one CE-E and one Product Engineer. Again, as in the previous study, work constraints limited the time available for the work and the sessions for the study had to be extended over a period of five months. The author first familiarised himself with the commodity under consideration, and together with people from the organisation established the team for the case study. In total 7 half-day meetings were held.

<u>Scenario</u>

The product under study was the vertical tail plane (VTP). The experts described that the interaction between the different groups of people involved in the commodity was not very good. CE-C were producing estimates based on parametric models without a clear understanding of what actually was changing in the product as such. CE-E were trying to analyse the cost estimates but there was not available detailed cost estimates of past product that could be utilised. Product engineers would request the cost on different product solutions they were developing but in each case they could not identify what was actually influencing the cost to change. A comment made by all the experts was that there was no transparency within CE.

The objective that was considered for this case study was to *identify the cost of the vertical tail plane* at the conceptual design stage and see if we could *improve the internal communication of CE.*

VTP Description

There are different designs of tails (figure 7-16). The main criterion for the design of the tail surfaces is the provision of adequate stability and control for the aircraft. There may be other requirements that have to be met by the tail (e.g. fuel tankage, structural support, etc.) but these are regarded as secondary to the main stability and control criteria. Technically this resolves into the provision of adequate moments about the aircraft centre of gravity to counteract de-stabilising forces from the aircraft geometry. The degree of stability and control to be provided will depend on the aircraft operational requirements. A large transport aircraft will need to be stable to gently position the aircraft, fly in emergency (engine-out) conditions and react to side winds. The vertical stabiliser box is a two or multi-spar structure with cover panels. The root of the box is fixed at the aft fuselage juncture with fittings or splices or the box spars terminate on bulkheads in the aft fuselage that are canted into the plane of the spars as show in figure 7-17, thus transmitting the fin loads directly into the fuselage structure and avoiding the fatigue-critical structural splices. *It is important to note that the sizing of the fin is specified by the aerodynamic requirements of the plane* (for more information please refer to Howe's textbook (Howe, 2000)).

Indeed the sizing was considered by the CE experts to be the most important "input" for their cost estimating process for this commodity in terms of the *specifications*. Cost estimators were given the size of the VTP and they had to identify how much it will cost. It has to be noted that the VTP does not change in every aircraft manufactured, consequently, *for this case study the team decided to develop VTP cost estimates for three different sizes*, each corresponding to a different class-size aircraft. *This is the only important specification the costs will be related to.*

From the PD and help from the cost estimators a template for the cost estimate was developed that can be found in appendix E4. Below in figure 7-20 part of that template is presented. Since the estimates were developed parametrically, the data needed by the estimator was the weight of the component, the hours of manufacture and the cost of materials and labour.

The author tried to identify data that he could use for developing a detailed bottom up estimate. *This was not possible* as it is not the way the company operated its cost estimating department. Cost estimating data was available in parametric estimates in the form of Excel spreadsheets or commercial parametric tools.

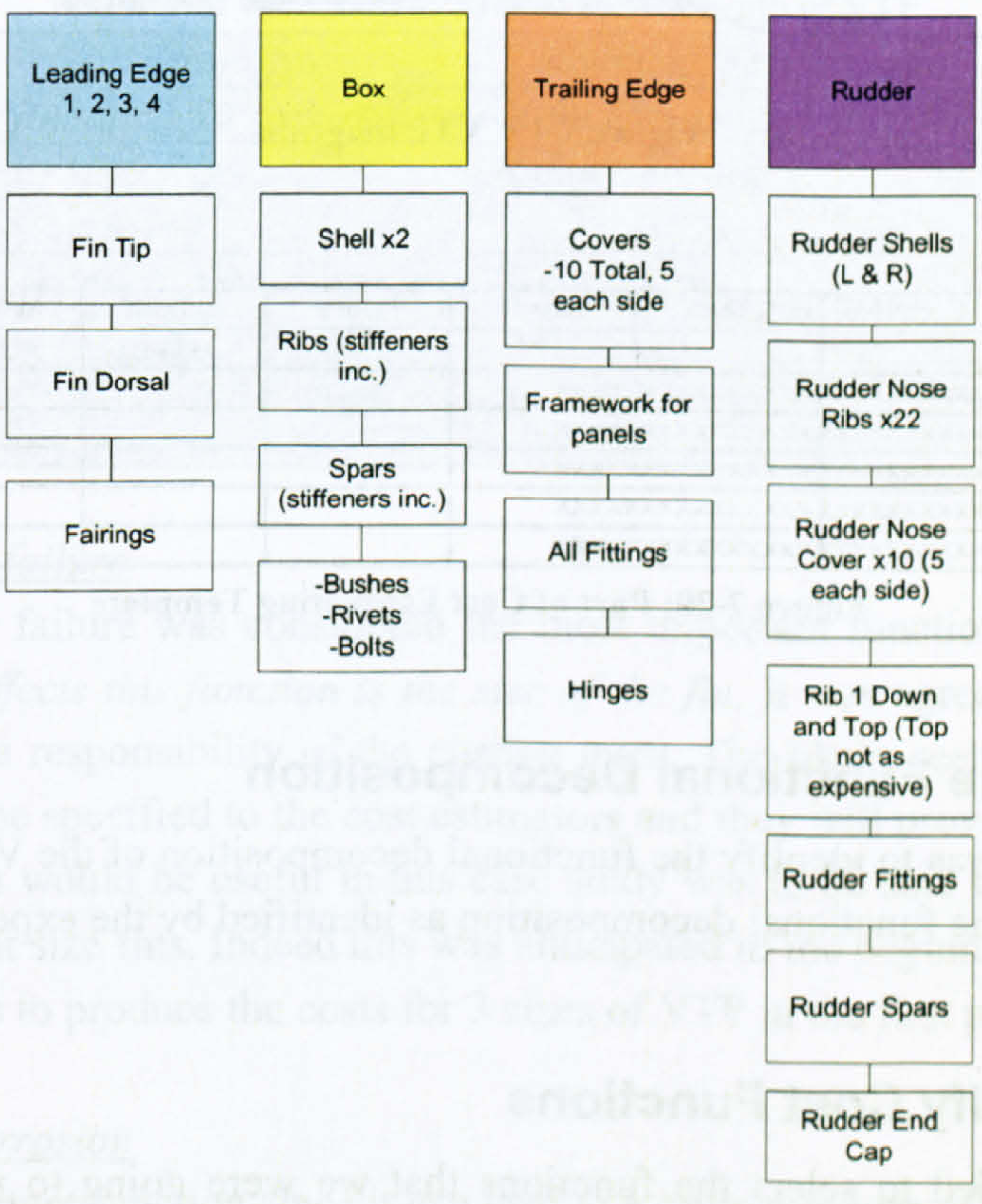


Figure 7-18: Product decomposition of VTP

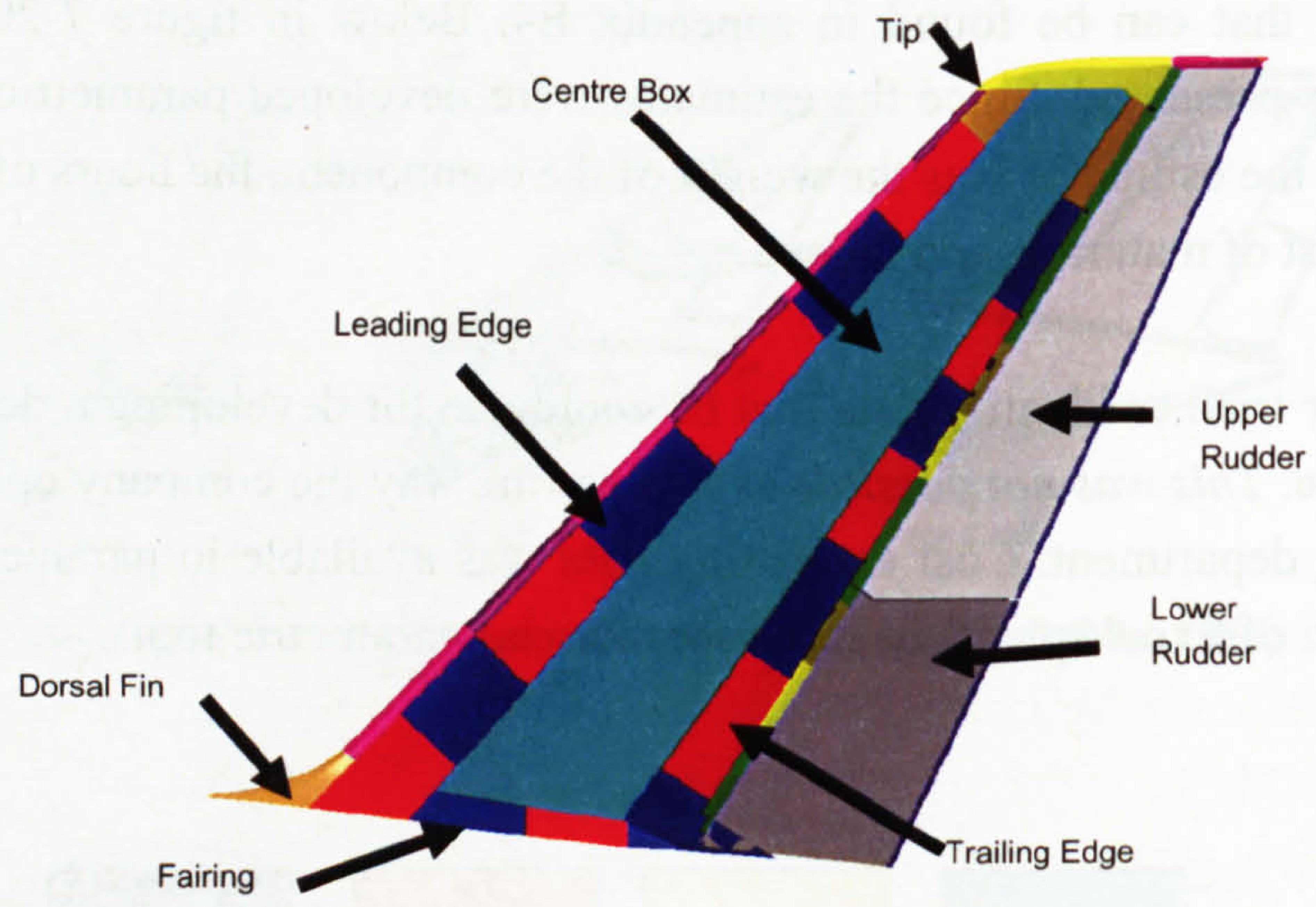


Figure 7-19: VTP diagram

Component	Serial No	Part Num.	Weight in KG	Hours	Labour in Euro	Material in Euro	Sum in Euro
Leading Edge 1	xxxxxxxxxx	xxxxxxxxxxxxxxx					
Leading Edge 2	xxxxxxxxxx	xxxxxxxxxxxxxxx					
Leading Edge 3	xxxxxxxxxx	xxxxxxxxxxxxxxx					
Leading Edge 4	xxxxxxxxxx	xxxxxxxxxxxxxxx					
Fin	xxxxxxxxxx	xxxxxxxxxxxxxxx					

Figure 7-20: Part of Cost Estimating Template

7.3.2. Define Functional Decomposition

The next step was to identify the functional decomposition of the VTP. Figure 7-21 demonstrates the functional decomposition as identified by the experts.

7.3.3. Identify Cost Functions

The team needed to select the functions that we were going to use for the later stages of the FUCE framework. The importance of the functions and the associate cost related to that function, as the experts could predict through their experience played a major part. The functions identified were:

1. Readjust for failure
2. Protect from Corrosion
3. Transfer aerodynamic loads
4. Protect from sudden impact

The rest of the functions, like in the previous case studies were considered to be common between products, thus having a constant cost estimating value. For example, in the case of the *'provide lightning protection'* function the author assumed that an almost identical assembly was required in each product that made it a constant part regardless of the VTP design. This was verified and accepted by the experts.

7.3.4. Define Product Parameters of Functions

The next stage of the FUCE methodology was to identify the product attributes that relate to the cost functions. Table 7-5 presents them as identified by the experts.

Table 7-5: Functional/Physical Relationship of VTP

Function	Physical Attributes
Readjust for failure	-VTP Sizing
Protect from Corrosion	-Leading Edge
Transfer aerodynamic loads	-Centre Box
Protect from sudden impact	-Leading Edge

Readjusting for failure

Readjusting for failure was considered the most important function. *The physical attribute that affects this function is the size of the fin.* It was agreed by the group that it was not a responsibility of the costing team. The likely scenarios were that the size would be specified to the cost estimators and they will provide the estimate of the fin. What would be useful in this case study was to be able to anticipate the cost for different size fins. Indeed this was anticipated in the beginning of the study and the aim was to produce the costs for 3 sizes of VTP in the first place.

Protect from corrosion

This is an important function since it can lead to a critical failure of the component. The leading edge was associated as this is, according to the experts interviewed the most likely place for corrosion.

Transfer aerodynamic loads

The centre box is the component that is responsible for this function as it has to withstand all the bending motions.

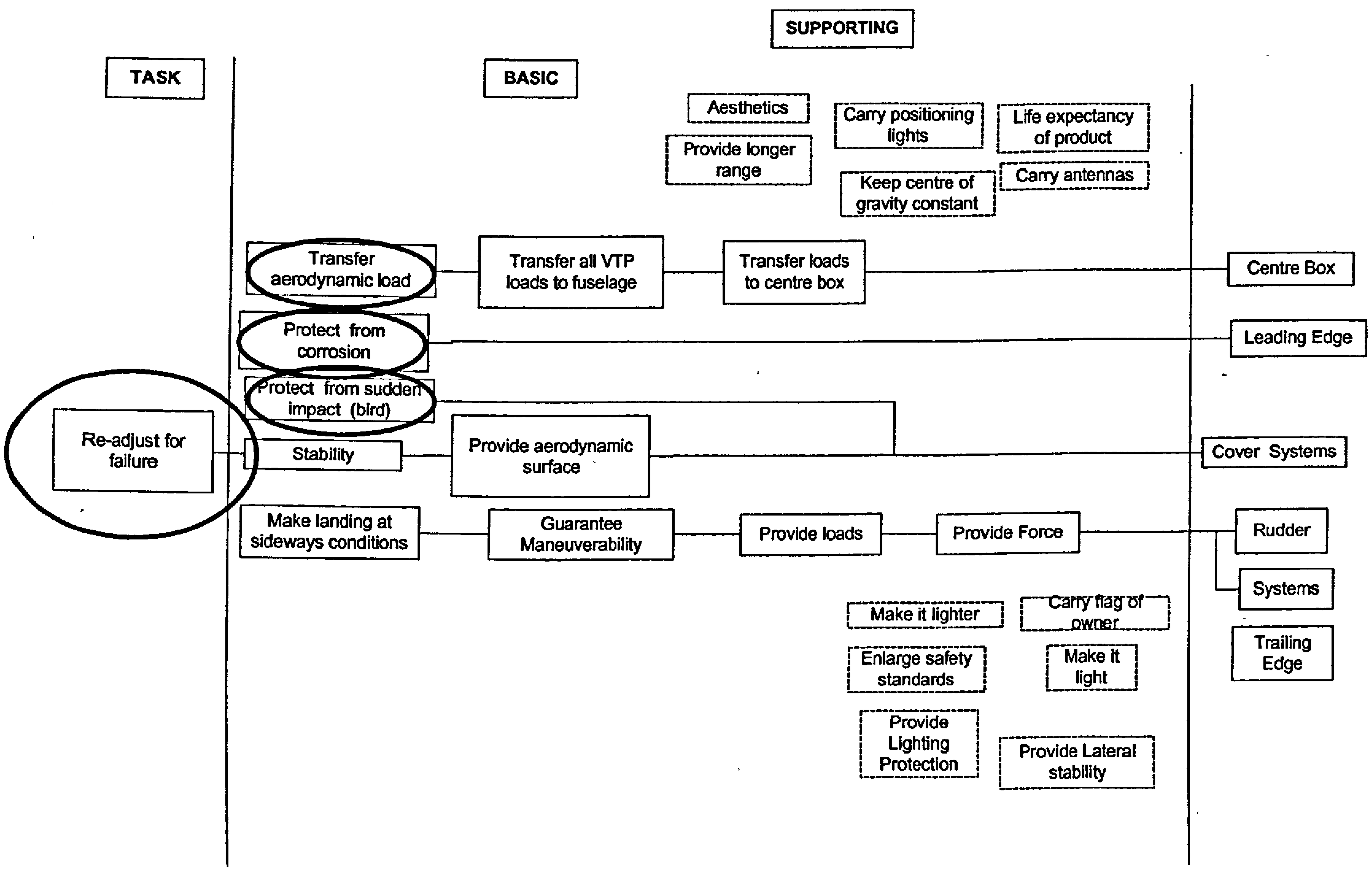


Figure 7-21: Functional Decomposition of VTP

Protect from sudden impact

It is often the case that through the journey of the aircraft, a bird or other debris will hit the VTP and the leading edge. Considering that the mass of the bird multiplied by the speed of the aeroplane, can result in a significant damage to the plane if certain precautions are not taken.

By identifying the product attributes that affect the functions CE-C could understand what where the most important functions that affect the cost of the VTP.

7.3.5. Create relationships between product attributes and parameters

After the product attributes were defined the team tried to create the relationships between the product's attributes and the parameters one could identify. Performing this process with the experts, certain parameters were identified that were affecting the product attributes (figures 7-22 and 7-23). Since it has been identified that the size of the fin changes according to the size of the aircraft, certain elements of the product will change linearly. This is due to the fact that some product components do not change design; they just become either smaller or larger or in other cases their quantity might change. These parameters are highlighted in yellow. Of course there are other attributes that can change completely, like for example, the leading edge panels, highlighted in orange in figure 7-23. They can either be made from honeycomb glass or honeycomb carbon.

It is important to note that this result is similar to the way parametric estimates are created. The cost is associated with weight or other quantifiable measurements, e.g. volume.

Now CE-C not only knew what attributes of the product are important but also could identify the actual product parameters that change.

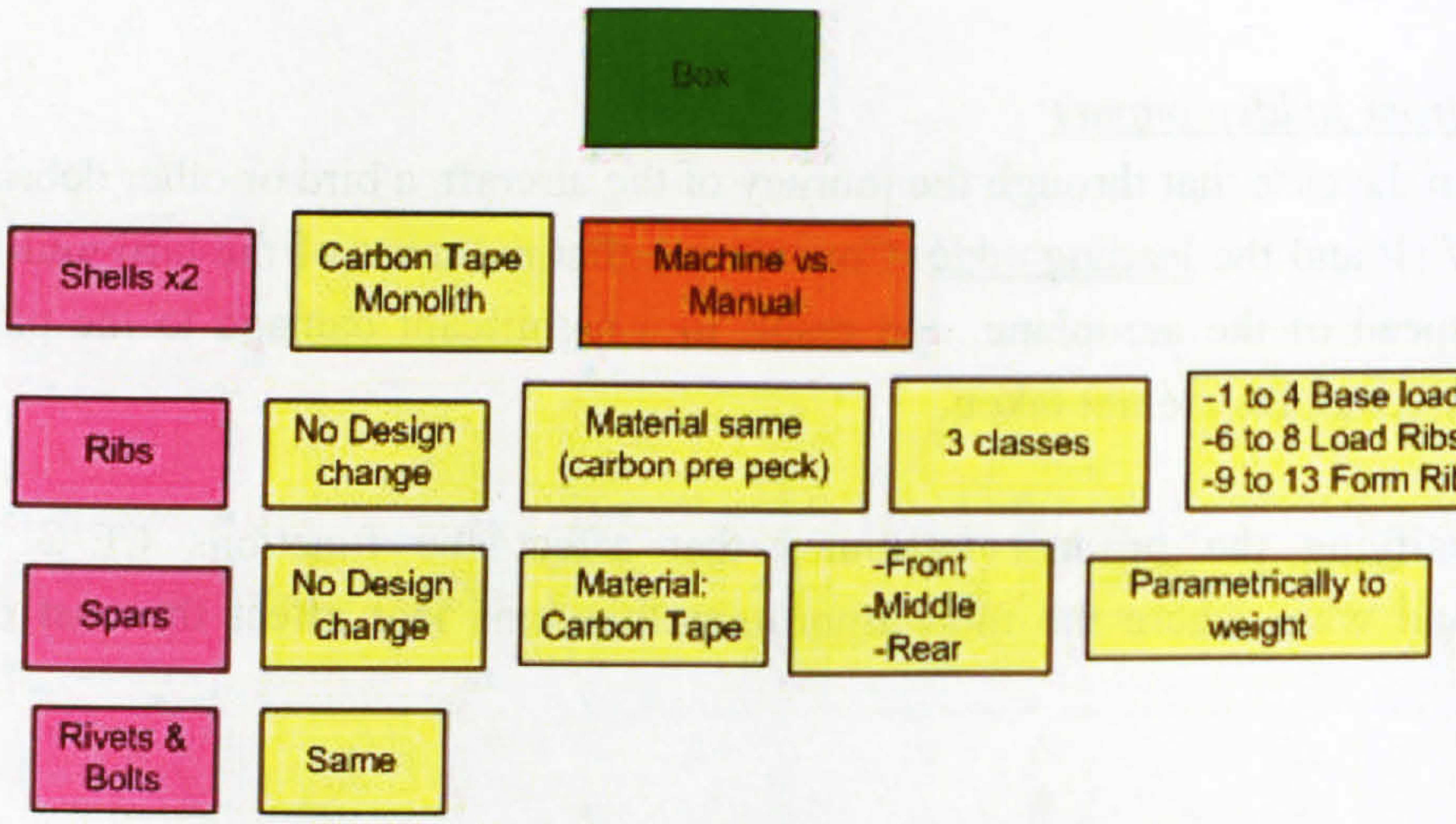


Figure 7-22: Product attributes analysis of centre box

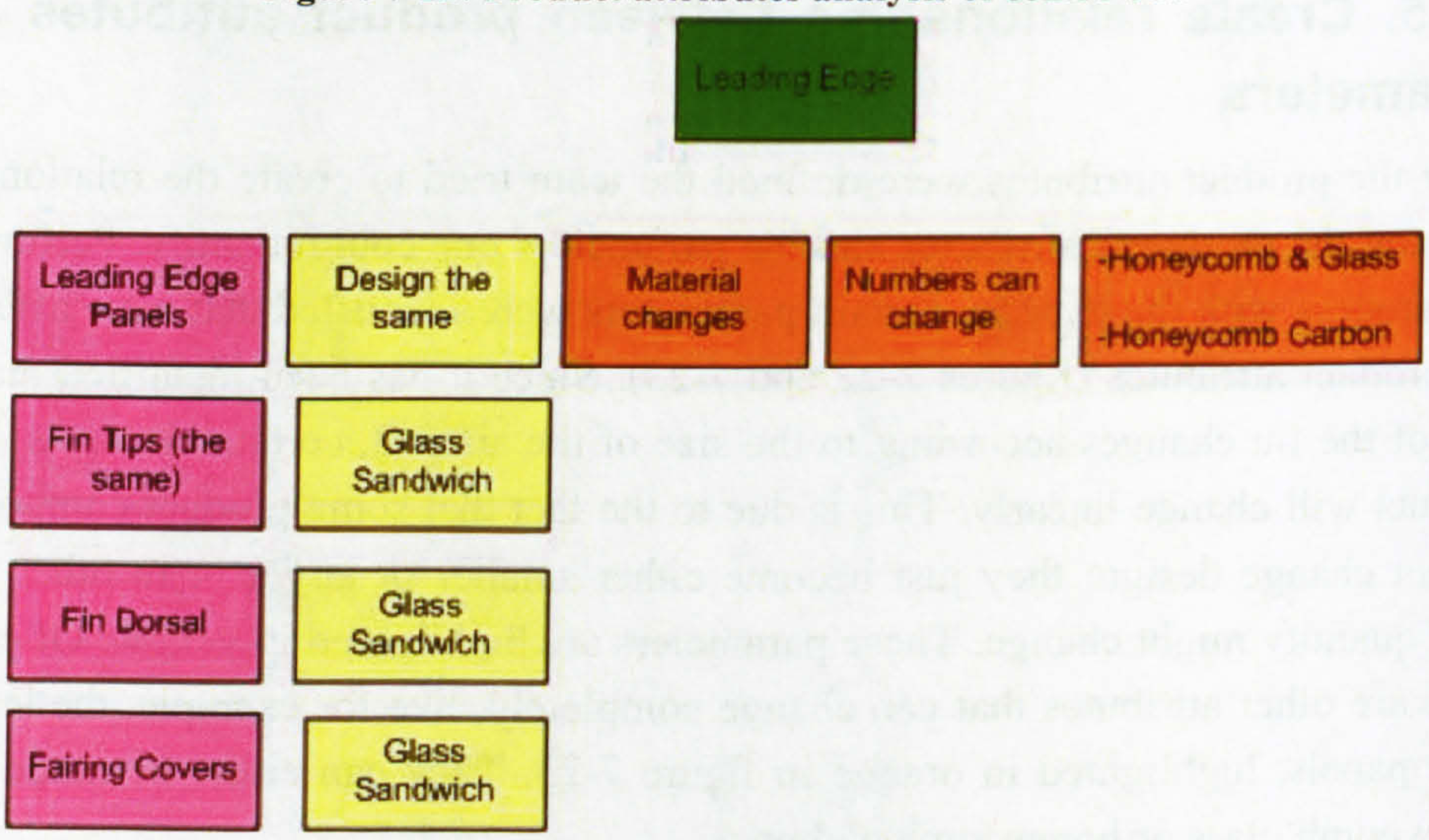


Figure 7-23: Product attributes analysis of the leading edge

Unfortunately, the relationships created were considered of great importance for the manufacturer to be revealed. It was agreed from the beginning of the study that if the manufacturer wanted something omitted from the study, that request would be granted. Almost all of the relationships omitted had to do with design type decisions.

7.3.6. Apply relationships to cost estimates.

The next step for the cost estimators now was to develop cost estimates for different sizes. The most important parameter identified by the estimators that affects the cost was the weight. The estimator would derive the cost of a future product based on cost per weight rates. For example, in figure 7-24 an example is shown where the cost of the VTP box is analysed to derive the cost per kilo for the shells, spars, ribs and fittings (template in appendix G5). The cost estimators use relationships like these to estimate the size of a bigger or smaller vertical tail plane. It has to be noted that this is the way cost estimators would normally prepare their parametric estimates.

Figure 7-24 to 7-26 demonstrate as an example the cost of the VTP Box for small, medium and large VTP assembly.

Plane1				
INPUT				
Small VTP				
Area	qm		22	
Height	m		5.9	
weight	kg		470	
OUTPUT				
Main Component		kg	€	€/kg
VTP Total		331	153,076	463
VTP Box		330.8	153,076	463
Shells		250	41540	166
Spars		42	38976	928
Ribs		25.4	51310	2,020
Fittings		13.4	21250	1,586

Figure 7-24: Cost of Box for a Small VTP

Plane2				
INPUT				
Medium VTP				
Area	qm		45	
Height	m		8.3	
weight	kg		1,180	
OUTPUT				
Main Component		kg	€	€/kg
VTP Total		578	275,537	477
VTP Box		577.8	275,537	477
Shells		436	69000	158
Spars		74.2	65472	882
Ribs		47.5	98065	2,065
Fittings		20.1	43000	2,139

Figure 7-25: Cost of Box for a Medium VTP

		Plane3		
Large VTP				
Area	qm		53	
Height	m		9.3	
weight	kg		1,440	

Main Component		kg	€	€/kg
VTP Total		676	381,773	565
VTP Box		675.722	381,773	565
Shells		504.8	85643	170
Spars		81.522	132159	1,621
Ribs		62.1	115379	1,858
Fittings		27.3	48592	1,780

Figure 7-26: Cost of Box for a Large VTP

Under normal conditions the cost estimators in the company would prepare estimates that look like the three ones described above. By following the FUCE methodology though, the experts have identified a series of parameters that change with regards to the size of the fin. For example, in figure 7-24, 7-25 and 7-26 the cost per kilo for the "Spars" are:

-Small: 928 €/kgr.
-Medium: 882 €/kgr.
-Large: 1,621 €/kgr.

Before the analysis of the case study, it was not clear to CE-C why the costs will vary. Also product engineers were not able to identify where the extra cost comes from. After the case study there is a series of assumptions that were documented and relationships created that were associated with this number. For example, the difference of the 'spars' cost estimate between a medium and a large spar was attributed to certain special design decisions related to the function '*protect against impact*'. Before only the person who made the assumption could understand this relationship, now with the application of FUCE, the assumptions were cleared to both CE-E and CE-C. As a result, there is a much clearer understanding of the product and the changes that are required for each manufacture.

7.3.7. Validation

At each step of the methodology all the participants were asked to verify that they were happy with the progress. At the beginning of the case study there were reservations from the CE-C with regards to the data availability. Indeed that was an issue with the development of the cost estimates. After the author explained the benefits of the FUCE framework and presented a previous case study, there was a desire from all the participants to use detailed estimating to derive the costs as they believed it would have the same positive results as it did in the automotives case. Of course as it was discussed in the beginning of the chapter, there was only parametric data available as in the aerospace organisation this was how they created their estimates.

After the results were obtained from the three sized VTP, the total cost estimates were close to the ones observed with the traditional parametric tools. What had been improved though was the understanding of all the participants with regards to the commodity. Because of the analysis of the functions and what changes to the product with regards to size, CE-C had an understanding of the different technologies employed to the product, and therefore could understand why the changes were actually occurred.

Overall the experts were happy with the results of the case study, although they were discussing to try and develop within the organisation an example with actual detailed data in order to present to management the full potential of the approach. It was agreed that this would take a lot of time to prepare.

Characteristic comments from the participants are presented, as captured by the author during the meetings, as qualitative evidence:

<u>Performance</u>

"The methodology is straight forward. It was not difficult to identify the functions of the product as they have always been the same. What takes time was to identify the different technologies employed in the different designs we have. Also the data was an issue as I told you before. If we had the detailed data I think the model would be much more useful to us"

<u>Accuracy</u>

"The accuracy is very good. This really is a parametric estimate, very similar to the ones we create. Since we utilise the same data, I see no reason to get different results"

Ease to Use

"The methodology is easy to use. But I believe a facilitator like you (the author) is needed to clarify certain circumstances""

Relevance

"I cannot imagine using this model every day; of course we do not build different planes every day. I believe that we could apply the FUCE methodology to certain commodities that we feel are important to us and to have the results created as a guide. The biggest benefit would be to the participants of the study as they will learn a lot about the different technologies in the product"

Integration with business

"I think that it will be very beneficial for our organisation to apply the FUCE methodology. The biggest benefit I can foresee, like it happened also in this case study, is that a much deeper understanding between the commercial and engineering people will be achieved. Traditionally we know that the cost will change depending on the requirements. What we did not know was ***why*** *the changes occurred. By applying the methodology we need to identify those parameters"*

Transferability

"I do not believe that this could be used to other components than hardware"

Integration of CE-C and CE-E

"We did achieve a better understanding of how engineers work. It was important for example to know that some materials will change if the skin (of the VTP) becomes larger. Before in my parametric model I could only see a number. Also the idea of being in the same room with the engineers is new to me. Usually we do not interact together"

Summary of Observations

The objective of this case study was to investigate the application of FUCE in the aerospace industry. The author wanted to see if the framework will improve the interaction between CE-C and CE-E.

- Both experts agreed that the interaction and understanding between CE-C and CE-E was improved due to FUCE. Now they could understand what was the reason behind certain changes to the cost estimates;
- Both experts participating in the study agreed that the FUCE framework would be better utilised with the application of detailed bottom-up

estimating. Although the estimates produced were relatively accurate, they were produced using the same method utilised in the company and therefore there was no extra advantage offered in the FUCE approach.

- Because the methodology involved both groups of CE, the experts commented in a positive way about the 'knowledge exchange' that occurred during those meetings between the two groups.
- All the participants agreed that the model could be applied in most of the hardware products in their industry.
- Both experts agreed that a more important consideration should be given to the development of detailed estimates in the aerospace industry. The benefits would include a lot more understanding of the costs and the FUCE framework could be applied with potentially the same benefits as in the automotive industry. The biggest limitation to this approach would be the time needed in order to develop the estimates.

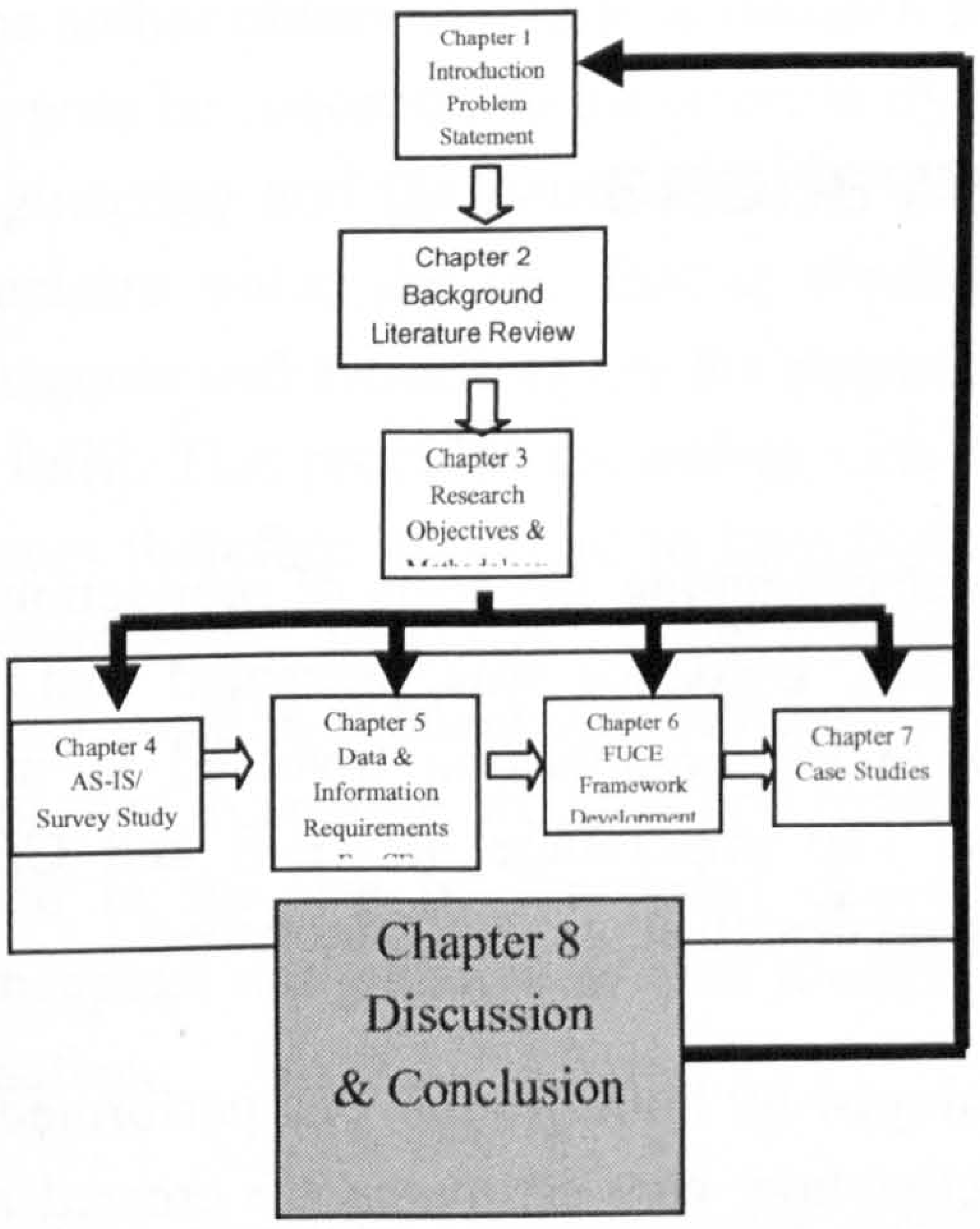
7.4. Summary

In this chapter the author presented two case studies using the FUCE framework. The first case in section 7.2 was another automotive part (sideshaft), but in this case it was comprised of smaller and fewer parts. The case resulted in success as the estimator could derive the cost of the sideshaft with only inputs the size of the engine of the car, the type of drive and the type of car. The results were validated and accepted by all the participants of the study.

The author tried also to apply FUCE to the aerospace industry (section 7.3) and the VTP, although the costing techniques utilised in the industry was that of parametric estimates. The framework was applied and estimates were derived. Unfortunately there was no detailed data to analyse the differences in the products produced in the past. Although the results were comparable to the once derived with parametric techniques, they lacked the detail that is offered by using detail bottom up estimates. In the next Chapter the whole thesis is discussed, including an analysis of the case studies.

THIS PAGE IS INTENTIONALLY LEFT BLANK

8. Discussion and Conclusions



The function-based cost estimating framework (FUCE) in Chapter 6 and the data infrastructure for cost estimating in Chapter 5 were the outcome of the literature review and the results presented in chapter 4. The literature review and results demonstrated that there is a need for improvements of the internal practices of cost estimating. In chapter 4 a survey study was carried out into the issues facing internal practices of cost estimating. One issue identified was the lack of information. This led to chapter 5 and the development of a data infrastructure for cost estimating. The other big issue facing CE-C and CE-E was their interaction at the conceptual design stage. This led to the development of the FUCE framework in Chapter 6.

The data infrastructure was created by 'mapping' the processes cost estimators perform and associating data for each step. Finally the resources of where this data could be potentially collected from were identified. The FUCE methodology was developed from a combination of the research finding, the literature and using the sponsoring company as a case study. The FUCE framework was further tested for relevance by developing another two case studies, one in automotive industry and one the aerospace.

Within this chapter the are discussed and concluded. This Chapter draws together everything that has been reported from both the work of others and the author's own research. The main aim of the chapter is:

Chapter Aim:
To discuss and conclude the implications of the research findings established in the thesis.

In Section 8.1, a summary of key observations is presented. In Section 8.2, the research contributions are discussed. In Section 8.3, the implications of implementing the results of this thesis are discussed. In Section 8.4, the limitations of the research are identified. In Section 8.5, areas for future research are discussed before drawing conclusions in Section 8.6.

8.1. Key Research Observations

8.1.1. Literature Review

The literature established the importance of estimating the costs of production as early as possible in the product life cycle. Evidence was presented that the manufacturing costs are most important to the organisation involved in mass production like the automotive industry. The importance of CE-E and CE-C working together, especially at the conceptual design stage was established.

A review of the different techniques employed by both groups was performed in order for the researcher to understand better how cost estimates are created and what the issues with each technique are. A different focus was observed for the two groups. The techniques employed traditionally within CE at the conceptual design stage, like parametric estimating (PE) and expert judgement (EJ), hinder the communication between cost estimators due to the "unspoken" assumptions made while creating the cost estimates. This lead to inconsistencies when another cost estimator tried to re-create the same cost estimate or try to understand it.

With PE, estimators end up arguing the costs based on the parameters they chose for their estimate instead of the actual product. For example the commercial packages used for this task have a "complexity factor". Complexity factors are provided based on examples, two estimators could argue on different values (1.5 or 1.3) therefore ignoring the product itself and the manufacturing challenges it might present and concentrate on those figures. Furthermore the models created do not provide sufficient explanation with regards to certain selection like materials and manufacturing process decisions, thus making it very difficult to understand and explain the estimate e.g. in a negotiation with a customer or a supplier. On the other hand, detailed bottom up estimating provides the detail needed to understand processes and materials but it was not applicable at the conceptual design stage. Detailed information is not available at that stage for the CE-E to develop an estimate. The author believed that the use of CERs could possibly be combined with the detailed bottom-up method, thus allowing the benefits of both techniques at the conceptual design stage.

The author observed a lack of research in the area of CE internal practices. For this purpose he concentrated his effort to try to learn from engineering design and value engineering and the issues around conceptual design stage. Many authors in the literature stated the fact that at conceptual design stage the inputs available to designers and estimators are the requirements and the functions the product needs to fulfil. This provided the author with further directions for his research analysis. It was therefore important to investigate the relationship between the conceptual design stage and CE. Value engineering and in particular the functional decomposition method was reviewed by the author. Although value engineering was used to analyse products and reduce their costs, not a lot of research had been done in the use of functional decompositions to estimate a new product at conceptual design stage or how it could help improve the internal cost estimating practice.

Another direction for improving the internal cost estimating practice was the development of a data infrastructure. Suitable information is the content of any communication which allows the creation and the utilisation of cost estimates. Information facilitates the interaction of people, material, equipment and money to reach at the profitable and competitive products. Correctness of information is important as poor information can cause multiple problems such as designs which are not optimised for manufacture or assembly, feeble investment justifications, and purchases of overpriced components.

Literature demonstrated that decisions are based often on inaccurate, incomplete and out of date information. That was because a cost estimate is a probabilistic assessment and therefore involves uncertainty. These decisions may be poor and result in considerable unnecessary expense. As cost estimates are mostly based on estimated information, it is necessary to truly understand how these estimates are composed and where possible sources of risks lie.

It was observed that design researchers face similar problems like cost estimators. Motivation and ideas for the development of the data infrastructure was gained from relevant research in the area of design. Characterisation of the information sources, the correct amount of information necessary and the issues associated with this information were reviewed from other researchers.

8.1.2. AS-IS: Survey Study

The key benefit of the AS IS study was to validate that the hypothesis of the research (the need for improvement of internal practices) is valid, and to highlight the potential problems that arise. For this purpose a questionnaire was developed and semi-structured interviews were conducted. The aim was identify any issues that exist between CE-C and CE-E, and help to identify the issues surrounding the data and information needs for cost estimating. The survey was conducted across different industries to encapsulate the most amounts of information and opinions with regards to the internal cost estimating practices.

An important observation of the AS IS study was the lack of a formalised approach in regards to a costing database. CE-E produces estimates often based on obsolete data. Wherever there is lack of a specific rate, the estimators assumes one based on their experience. Other cases observed throughout this study was the use of different rates for the same labour or machine used within the same department. The reason for that was that many estimators had their own set of data based on catalogues and brochure provided by machine vendors and suppliers. Most companies agreed on the point that a common data infrastructure would be beneficial; it was often referred to with slight modifications, but generally went along similar lines, of containing general costing information, such as overhead costs, material , labour costs, tooling and so forth.

The importance of cost estimating at the conceptual design stage was presented by CE-C. A number of issues were raised with regards to problems faced by estimators during the specification of the product. There was a lack of understanding how the specifications impact on cost, before the actual design was available, for the CE-E to create a cost estimate. CE-E in order to produce the estimate requires a physical part, a detailed design or detailed specifications. If a decision was made that this information was not enough, he will try to contact an engineer or the supplier who will be involved in building the specific component. Once he is satisfied with his understanding of the product he will construct an estimate.

There were often discrepancies between the cost engineer's earlier quotes, and the acceptability of these figures from the commercial group. This difference of proposed costs, as stated by several industry representatives, came from the difference of emphasis or importance allocated to the various aspects of the project as well as the different understanding that exist between the commercial and engineering groups.

The main reasons were that:

▪	The communication of the product requirements and specifications from the commercial to the engineering people were not well established. There was no framework linking the product functions to a cost estimating template.
▪	The data available to the cost engineers to perform their estimates was not of appropriate detail. It was noted throughout the survey that organisations do not have a detailed costing database in order to produce estimates. Data was usually collected from supplier quotes or different financial systems within the company.

Several challenges were raised through the AS IS study and the interaction with the Cost estimating experts in the automotive industry:

- Lack of resources for cost estimation
- Difficulties to get access to information
- Correctness of information
- Lack of understanding of cost estimation information

8.1.3. Data and Information Requirements

With the challenges identified in the AS-IS stage the author decided to develop a data infrastructure for cost estimating. The author stated the need to identify a common cost estimating process. If a process could be established that was common across the automotive industry, then a data infrastructure that related to that process would be of great benefit to the whole cost estimating community in the automotive industry.

The author mapped different processes using tools like X-Pat and IDEF3 to identify the "objects" associated with the process. The common process identified was the bottom up cost estimating. The necessary data elements were identified for completing the process. Furthermore the resources where someone could retrieve the information were presented. In summary the following observations were made:

<u>The Process Models</u>

When analysing benchmarking and detailed cost estimating activities conducted in the companies, it was found that both are using similar cost elements. Based on this finding a single common cost estimation process model for the automotive industry was developed. The model was based partially on the work of the AS IS and on the process maps presented in Appendix C.

The Data Infrastructure

The development was based on the cost elements and resources identified. Further analysis was conducted for the creation of the Web Portal, which was the physical presentation of the information infrastructure. First the cost elements were categorised. The categorisation was a consensus that fulfilled major requirements of the automotive companies. The categorisation produced diagrams containing all the cost elements.

The research elicited several resources used by cost estimators in the automotive industry. The number of specific sources was observed to be great. The large amount of different sources suggests that there is no standard way how information sources should be used. The cost estimators agreed on this during the interviews. This had led sometimes to situations where different cost estimators making similar estimates have different results because of the choice of the resource. The sources were classified under three major headings; internal resources, supplier resources and external environment resources. The internal resources provide mostly technical information of a component and expertise for particular situations. Supplier resources were the main source of information. Cost estimators could ask variety of information from the supplier but the validation of the provided information was an issue. Therefore it was normal practice to source information from the external environment for this validation.

It was found that cost estimators use resources for getting two different types of information; cost information and information needed to deduce the cost. Also it was observed that there is a difference between the information available from the resources and the actual information used. That is only portion of data available was used, therefore the used cost elements are mere subset of all the information available. The author selected 80 cost elements from these resources. A cost element was selected if cost estimators considered it to be both relevant and actually usable for the creation of a cost estimate.

Web Portal

Data templates (web pages) were created for the web portal. These templates defined each cost element used in the automotive industry. The content of data templates was based on the identified best practises for each individual cost element. The templates explained in detail why cost elements are relevant for cost estimation and identify possible sources where cost estimators can find values for them. Each created data template answers on at least the following questions; what is the cost element, why it is used, what information sources are available for it, and how to validate the information.

8.1.4. Function-based Cost Estimating

This chapter addressed the issue of interaction between commercial and engineering disciplines within cost estimating at the conceptual design stage. It introduced the concept of **'Function-based cost estimating'** (FUCE) as a linkage between commercial and engineering activities.

So early in a project the types of requests CE-C will ask the CE-E were for example:

- *"How much will the exhaust system cost if we increase the engine capacity of the vehicle?" or;*
- *"How much will it cost to add all-wheel drive to the vehicle? With a small capacity engine or a large one"*

This type of questions a CE-E will receive, were *un-quantified requests*. The CE-C were not looking for detailed estimates but for an approximate cost in order to be able to make decisions. CE-E, following the bottom-up process will try to acquire more information regarding the product in question and try to use their expert judgement in order to provide the answer. There were a series of problems associated with this approach:

- CE-E make assumptions that were not documented;
- Results were not repeatable;
- Results could not be explained easily to another cost estimator as they were based on the assumptions of an individual and were not necessarily the most complete.
- The whole process was not systematic.

In many cases CE-E make assumptions that were not agreed with engineers, leading to errors in the cost estimate.

A methodology was presented that allowed cost estimators to base their estimates on the functional characteristics of their product. Using data from past product and the knowledge of the experts, relationships were created in the form of equations or tables that could be associated to elements of the cost estimate and predict the cost behaviour of the product. Two examples were presented based on the automotive industry. The models proved that it was possible to create estimates based on functions, thus integrating commercial and engineering knowledge within cost estimating. The author believed that this approach would help to improve the communication between the disciplines involved in cost estimating and assist estimators at conceptual design stage.

Validation

The FUCE methodology and the final models created for the two case studies in the automotive industry were validated with the experts. Validation of the methodology was performed at each step. Once the final model was created, the researcher organised a workshop with all the participants of the case study.

The models created were tested for their accuracy with regards to the final costs produced. The experts agreed that the cost results were realistic; furthermore what was important to them was the direction of those costs, if they were going upwards or downwards, depending on the inputs they specified.

The model was tested for its completeness. In general the users were very happy with the relationships created in the model. A recommendation was made by a user that the model could be potentially refined even more in order to make it more detailed. Although this comment found agreement in principle by the other participants, they all agreed that the time and resources spend on this effort would not be of a great benefit, as this model was created to represent the conceptual design stage. The indication of the costs produced was already satisfactory.

The framework was finally tested for its ability to improve interaction between CE-C and CE-E. The participants commented with positive words about the two aspects of the framework, the methodology followed and the actual model developed. The participants commented that the methodology allowed the different groups of CE to interact and understand how the different requirements affected the functions and the cost of the product. CE-C could get an understanding of the engineering implications of their requests. On the other hand CE-E had the opportunity to create the estimate in collaboration with the CE-C. This helped clear any misunderstanding CE-C had with regards to the assumptions made during its creation.

The experts agreed that the cost model created could be used for a considerable length of time unchanged. That allowed CE-C to create cost estimates with regards to target cost and feasibility studies in a matter of minutes with all the correct assumptions made, instead of the much longer periods required before. On the other hand, CE-E were satisfied that they had the "ownership of the estimate and the rules and assumptions were primarily created by them, therefore the cost should be in accordance to their expectations.

Overall all the experts agreed that this approach minimised the time necessary to create cost estimates at the conceptual design stage where both CE-C and CE-E had to collaborate. Although it needed a considerable amount of commitment from all participants for the creation of the model in the first place.

<u>Testing the Relevance with other Industry</u>

Except the validation with the research sponsor for the first case study and another automotive company for the second, the FUCE framework was also applied to the aerospace industry. The case study was developed with three experts in a big aerospace manufacturer. The results were positive for this industry. Although the accuracy of the estimates produced was not better than the ones available in the organisation (based on parametric estimating techniques), the participants benefited from the methodology as a better understanding of the engineering complexities and choices made to the product was achieved. CE-C could understand why certain changes were made in the cost estimate. All the participants were interested in the FUCE framework

8.2. Research Contributions

This research has significantly contributed to understanding the internal costing practices when creating estimates at the conceptual design stage. It has introduced a data infrastructure for cost estimators involved in the automotive industry and identified the resources available for this data. It has developed a framework that associates product functions to cost estimates at the conceptual design stage with contributions from both Commercial and Engineering groups of Cost Estimating. This research has managed to combine the advantages of bottom up estimating to provide as much detail as possible at the conceptual design stage. This was demonstrated through the development of two cases studies in the automotive industry. The contribution to knowledge is clearly identified in the following points:

Research Contributions:

- This research identified through literature the importance of CE-C and CE-E working together and the different cost estimating techniques employed by each group. Also the lack, and consequently the significance, of a data infrastructure for cost estimators in the automotive industry were observed.

- The research identified from an industrial survey that there was a lack of interaction between commercial and engineering people within cost estimating at the conceptual design stage. This is the major bottleneck in the CE internal practice. There were two main reasons for this. One was the lack of a common, coherent data infrastructure for cost estimators (this supports the observations from the literature review). The other was the lack of a common framework that brings those two groups together to develop the cost estimates.

- This research identified the data and information required to develop cost estimates for the automotive industry together with an explanation of why they are needed and where they could be found.

- This research developed a systematic and consistent framework where both commercial and engineering people of CE could prepare a cost estimate together for a specific commodity that could represent the cost at the conceptual design stage for different specifications using past experience.

8.3. Data Infrastructure and FUCE Implementation Issues

The result of this research provided a data infrastructure with all the elements needed to develop a cost estimate for the automotive industry. Explanations of why you need the specific cost and where it could be found were provided. The infrastructure was presented in the form of a web portal. The web portal was a complete working model that was provided to the sponsoring companies for utilisation.

The research in the FUCE framework provided a methodology where CE-C and CE-C could develop cost estimates based on the analysis of product functions and utilisation of detailed cost estimates. A handbook in using FUCE is also provided to the sponsoring companies.

8.3.1. Technical Issues

Data Infrastructure

A data infrastructure can be represented in different ways. In this research a website was used to demonstrate the concept. This provided a cost effective and technically less challenging approach for developing and testing the concept. Companies could implement the portal as part of their intranet (company internet). Text pages providing the links to other relevant information like the resources of where the information could be found. Companies using existing software vendors could integrate the infrastructure with a cost estimating database (not developed in this research) and therefore not only provide an explanation of the information but the user would actually retrieve a costing rate. Using commercially available professional will further enhance the capability and the use objectives of the data infrastructure.

FUCE

The methodology of how to implement the FUCE was quite clear as all the experts agreed. The representation of the model and the relationships created was performed by the author using MS Excel. Again this was done as it provided an inexpensive method for developing and testing the research. A company using vendor software could integrate the potentially created models with their database in order to update cost rates and details on the estimate automatically.

The aerospace industry faces an extra technical issue, that of the detailed estimating. Traditionally estimates are developed parametrically thus lacking the necessary detail to see great benefits from the application of FUCE. If aerospace organisation wanted to see the full benefits, a significant amount of resources would have to go into the development of such infrastructure.

Both the data infrastructure and the FUCE models would need to be maintained. Changes to the way information is collected from other software applications, or changes to the FUCE models will need to be implemented. If a professional software developer provide the application, the implications are not great. If the application is developed in-house, then the company needs to be aware of all the potential risks with regards to software and hardware issues.

8.3.2. Financial Issues

The financial implications need to be assessed of implementing the data infrastructure and the FUCE framework

Data Infrastructure

The author used a website application to create the data infrastructure, therefore the financial cost will be kept to a minimum. Only if the user company wants to implement the results in a different, more complicated way will the costs be raised.

FUCE

The cost estimates created with FUCE are company specific and one is needed for every commodity. What is generic though is the framework.

The cost models were created using Excel. Since this type of expertise is widely available in engineering companies, the cost should be kept to a minimum. Nonetheless, the models are not universally applicable. Different commodities will have more or less complicated models, based on the amount of relationships created between functions and cost elements. The development of the models will require cost estimators to invest time in documenting assumptions and developing the rational between cost elements and product functions. This will increase the cost of the development

In order to ensure that the investment in the development of the models is good value for money, the added benefits of this research need to be explained to both senior management and end users. This include a better understanding of the assumption and rational used by different groups within the company, the development of cost estimates that produce a competitive advantage during negotiation with suppliers, improved confidence on the estimates produced and on the reusability of those estimates within the organisation when new products have to be developed.

8.3.3. Cultural Issues

Cultural Issues are usually a big contributor to the difficulty organisations face to change. In the automotive industry both the data infrastructure and the FUCE framework found great appeal. Indeed a couple of organisations plan to expand the models and apply FUCE to further commodities. This was'not of great surprise as the research direction was formed after a survey in the automotive industry. FUCE also assists in the demise of cultural barriers, as during its implementation it allows CE-C and CE-E to work together to develop the cost estimate.

The application of the FUCE tool in the aerospace industry is more challenging. This is due to the fact that the industry traditionally uses parametric estimating techniques. Nonetheless, it should be noted that during the testing and validation phase of this research, the users form the aerospace industry were very satisfied with the results produced be the FUCE framework.

8.4. Research Limitations

8.4.1. Research Methodology

The research of this thesis was based on a qualitative approach. As mentioned earlier in Chapter 3, the data analysis of this approach is prone to bias, and the validation and generalisation of the results is very difficult to achieve.

One of the main reasons for using case studies in this thesis was the fact that the research was industrially sponsored. This provided the right environment for developing case studies. Nonetheless the choice of case studies was limited to the options available provided by the companies and such, the results and the development of ideas included in this thesis may have been biased.

The author spent a great deal of his time within the sponsoring companies and interviewed its experts. This prolonged exposure can lead to biased analysis of data that is influence by the experts the author spent most of his time within the costing department. This can lead to the formulation of new ideas that cannot be generalised for the whole scope of this research. In order to counter this potential limitation, the author used different collection techniques and reviewed as many different sources of information as possible. The results were either documented or recorded in tapes and archival records that could be used for auditing the opinion of experts were collected where possible. This approach, although it does not eliminate the bias completely, it can allow other researchers to understand the reasoning process followed by the author in producing the results of this thesis.

Since the case studies were developed within companies, both in the automotive and defence sector, a number of interviews was not documented and data was not always collected. This was due to the confidential nature of the information. The author had to rely on his notes and memory and as a result the data collection might not has been as accurate as possible. In order to reduce the bias, the author interviewed a number of experts.

The qualitative approach chosen by the author required a high level of interaction with people. Interpersonal skills were vital for the collection of data. As it happens outside a laboratory environment, the conditions are never optimum and are influenced by unpredictable parameters. A lot of knowledge with regards to the processes followed by the companies was obtained during informal meeting and discussions in the corridors of the department. This insights were not properly recorded so that they are available as auditable information. In hindsight, an ethnographic approach could have been employed by the author to better documents the data available.

8.4.2. Data and Information Infrastructure

<u>IDEF3 Process Modelling</u>

This process modelling technique and its representation of results is so concise that only people with the relevant expertise or the participants to this process can understand and interpret the results. Maybe other process modelling techniques would provide a better way of representing the processes.

IDEF3 requires a vendor software, therefore only people with access to the software can see all the information included in the models. Due to the nature of the software, some data could not be capture directly by the software and was included by the author in a different format. This increased the research bias. It would have been useful if more than one person was recording the information in order to provide a sense of validation and to capture better data. Finally, "what-if" scenarios could not be produces with this method

The models were validated by the experts that assisted in their development and therefore the subject bias is increased (see section 3.3.4). The involvement of other experts from different companies but the same domain would be preferred.

<u>Industry Support</u>

This research was dependent heavily on the resources and support from the industry. Two major issues that limited the research arise from this fact:

First, the knowledge was elicited from experienced cost estimators. The selection of senior people was necessary as expert judgement is necessary in the cost estimation. The availability of expert's time was a hindrance during the whole research. This limited the duration of interviews.

Second, there are a limited number of the automotive companies in UK. During the analysis of information it became obvious that interviewed cost estimators have quite a similar understanding. A wider range of companies and cost estimators' backgrounds would increase the scope of the infrastructure. The narrow scope caused the limitation of benchmarking only to the technical side. The findings did not support strongly enough the commercial decision-making (e.g. supplier selection) to be included into the detailed analysis.

Cost Elements

The cost elements described in this thesis concentrates on manufacturing costs. In the overhead category other costs are discussed. Two different types of limitations were identified for elicited cost elements:

First, the cost elements are generic therefore suitable for wider range of automotive companies. This works fine for elements, such profit margin. However most notably specifications, e.g. machine specifications were abstracted. Expert judgement is used when cost estimating, e.g. the impact of machine specification on the machine selection. This information is process, or machine specific. The elicitation of this type expert knowledge is requires plenty of time and effort from a company.

Second, the interviewed cost estimators were mostly concerned with the manufacturing costs. The research found that they are not designers or commercial people (to be deleted). The cost estimators acknowledged that e.g. financial information is needed but this type of analysis is not (normally) done by cost estimators. Similarly technical details of engineering designing are not (normally) known by a cost estimator. The existence of this type of qualitative knowledge was acknowledged by the cost estimators but the interviewing was not the correct method for the elicitation of them. Also the interviewed cost estimators were not specialist in those areas.

8.4.3. Function-based cost estimating (FUCE)

The FUCE methodology was developed having in mind the analysis of relatively small components. This approach could not be applied to a whole vehicle as the number of functions associated with it would be so great that would make the model unworkable. The FUCE model developed for the case studies followed a discrete approach. That means if the parameters selected as 'input' for the model also affected other functions of some other part of the vehicle, they were not documented. That means that the development of the vehicle in a single FUCE model would be extremely difficult.

The cost estimates and the data used for the development of the relationships were acquired from the sponsoring company. The terminology used in the estimates may not represent other industries.

Excel was used for the development of the prototype as the author possessed the necessary knowledge. A better approach could have been to employ a programming language that could develop a prototype that could be linked with other in-house software application like databases.

The methodology itself does not explain itself sufficiently. There is a need for a facilitator to guide the participants through the process of developing the FUCE model.

<u>Validation</u>
The author chose to use qualitative validation. Due to the lack of experts' availability this was the best approach to elicit observation. Furthermore qualitative validation provided a deeper understanding of peoples' views.

There was a limited number of contributors in the case studies. Although they agreed that the framework and the model created would be useful for them, the author would have liked to see the application of FUCE as an observer to another case study to see how the experts would cope by themselves.
The validation of the framework was performed together with two experts who were involved in the development of the case study; this increased the possibility for subject bias (see Chapter 6). In order to reduce this bias, the author validated the results with two participants of the second case studies. Despite of that, this research cannot claim that the conclusions of this work represent everybody within the companies used in the case studies.

Aerospace Industry

Aerospace industry traditionally prepares estimates using parametric tools and data. The FUCE framework and the data infrastructure suggested in this thesis were primarily developed to assist automotive manufacturers to develop better estimates at the conceptual design stage. Indeed the source of where information could be retrieved that was present in the web portal is specific to automotive companies. That is the reason that the data infrastructure was not validated in the aerospace sector.

The FUCE framework was applied to a case study in the aerospace industry (Chapter 7). The experts agreed that although the model created was useful to them, it was not possible to achieve the same type of results like in the automotive industry. The problem was the lack of detailed data. The data available in the company was based on historical data. The newer estimates created, were also based on the previous estimate and so on. This produced an accumulation of errors in the parametric estimates. The advantage of the FUCE approach was the use of detailed data in order to highlight the changes in the product. In this case this was only achieved through applying the methodology and identifying what was changing in the product. What was not possible was to quantify that change.

8.5. Future Research

The importance of the internal practices within cost estimating has been established in this thesis. The evidence suggest that it is an important issue for the different groups of CE to interact well yet no research can be found on the area yet. This was especially so within the conceptual stage of design, of complex hardware product in the automotive domain. The author suggests that a more extensive survey than the one conducted in this research is carried out that encompasses estimators from other industries.

During his research the author identified a lack of literature and a lack of collaboration between the practices of Cost Management and Cost Estimating in big organisations. Cost management needs cost estimates in order to perform its function; nonetheless there was a lack of literature in this matter. It seems that there is a trend for those two areas to have separate directions, instead of complementing each other. Thus there is a need for more detailed analysis of those two domains in order to improve the costing practices, not only at the conceptual design stage, but also in the whole product life cycle.

The research identified a data infrastructure for cost estimating in the automotive industry. It explained why this data is needed and where it could be found. The next logical step for research would be to actually capture this data and provide it through a database. Catalogue of data and information could be created for different industries that could be used as "best in class" rates. If enough unanimous agreement could be achieved across certain industries, then this database could be used by all companies as a reference point.

The FUCE framework (the methodology and the model) developed during this research was found to be very useful to the automotive sector. The methodology captured the product functions and created a relationship between product attributes that affect the functions and costs. These relationships captured, and in effect documented, the assumptions and the rationale of the estimators with regards to the product. With more research an automated approach in terms of a software could be produced that will guide the experts in following the methodology. Also the assumptions and relationships could be captured in a database that future experts could retrieve much easier.

More research is required in order to include an 'add in' capability to the functional decomposition. The author although suggested how to add a new function in the literature (section2.3.2) and in the methodology development (section 6.2), he did not actually demonstrate an example of this. The reason was that in the products reviewed this was not possible.

The models created in Excel provided the complete cost estimate with the rates used. The actual cost rates were considered by companies of great importance and not something that could be shared with suppliers or competitors. More research in the area of how to represent the result of the FUCE model would be beneficial for these purposes. Instead of actual rates a colour-coded approach could be used that will warn the user if the cost estimate created is over-valued or under-valued. Another approach could be in actually hiding the rates and providing 'multipliers to the different cost elements, by that allowing the estimator or any other user to understand the implications of his selections to the model but not being able to see the actual costs.

8.6. Conclusions

The research has achieved all the objectives presented in chapter 3. The main conclusions from the research are presented below

a) It is observed that there is a lack of research in understanding issues relating improvement of CE internal practice.
b) It is observed that CE internal practice can be improved by enhancing interaction between commercial and engineering groups involved in CE.
c) The research has identified data and information required for cost estimating in the automotive sector. The data and information is categorised in six major categories and sources identified.
d) The thesis presents a data and information infrastructure that implements the data and information requirements identified. The infrastructure improves communication between CE-C and CE-E. This better understanding helps in improving the cost estimating internal practice within the automotive industry.
e) The thesis demonstrates a function-based cost estimation (FUCE) framework to improve interaction between CE-C and CE-E at the conceptual design stage within the automotive sector. This is a systematic approach to link the two groups for CE. The framework is validated with two case studies in the automotive sector. Once adopted the FUCE framework improves CE internal practice.
f) FUCE framework is then applied to an aerospace product. The case study identifies the improved interaction between CE-C and CE-E is the major contribution to improve CE internal practice within the industry.

THIS PAGE IS INTENTIONALLY LEFT BLANK

References

AACE (2000). AACE international recommended practices and standards. AACE International, CDROM, ITEM NUMBER: 4060-05.

Aderoba, A. (1997). A generalised cost-estimation model for job shops, In: *International journal of production economics*, 53, 257-263.

Adesola, B. Roy, R. and Thornton, S. (2001). XPat: a tool for manufacturing knowledge elicitation. In: *Roy, R. (ed.). Industrial knowledge management: a micro-level approach.* Springer, London.

Alaiaga, M and Gunderson B. (2002*) Interactive Statistics*, [Thousand Oaks] Sage Publishing, USA.

Asiedu Y. and Gu, P. (1998). Product life cycle cost analysis: state of the art review. In: *International Journal of Production Research* 36/4, 883908.

BAE SYSTEMS (2001). *About BAE SYSTEMS.* Corporate Information, http://www.bae.co.uk/, (Accessed June 2001)

Balsley, H.L. (1970). *Quantitative research methods for business and economics.* New York: Random House.

Bashir, H. A. and Thomson, V. (2001). Models for estimating design effort and time. In: *Design studies*, 22(2), 141-155.

Benyon, D. (1990). *Information and data modelling.* Blackwell Scientific, Oxford.

Blommaert, A.A.M. and Blommaert J.M.J. (1998). *Bedrijfseconomische analyses,* 3rd ed., Houten, Educatieve Partners Nederland BV.

Börjesson, S. (1994). What kind of activity-based information does your purpose require? In: *International journal of operations and production management.* 14(12), 79-99.

Bogdan, R., & Taylor, S.J. (1975). *Introduction to qualitative research methods.* New York: John Wiley.

Boothroyd, G. and Dewhurst, P. (1987). *Product Design for Assembly Handbook.* Wakefield, RI: Boothroyd Dewhurst, Inc.

Boothroyd, G. and Dewhurst, P. (1991). Product design for manufacture and assembly, In: *Design for Manufacture.* (eds. Corbett, J., Dooner, M., Meleka, J., and Pym, C.). Wokingham, England: Addison-Wesley Publishing Co.

Brimson, J. A. (1991). *Activity Accounting.* New York: John Wiley & Sons, Inc..

Brinke, E. (2002). Costing support and cost control in manufacturing - A cost estimation tool applied in the sheet metal domain; PhD Thesis, University of Ultrecht, The Netherlands.

Burns, R. (2000). *Introduction to research methods.* Sage Publications Limited, International Edition, London, UK

Busby, J.S. (1997). The limited informativeness of resource discrepancy feedback to designers. In: *International journal of operations and production management,* 17(6), 630-646.

Bytheway, C.W. (1971) .FAST Diagrams For Creative Functional Analysis. In *SAVE Communications and Journal of Value Engineering,* Vol. 71-3, 6-10.

Cassel, D. (1981). *Introduction to computers and information processing.* Reston Publishing Company, Reston.

Chen, Y.S. (1997). Examination of U.S.-based Japanese subsidiaries: evidence of the transfer of the Japanese strategic cost management. In: *The international journal of accounting,* 32(4), 417-440.

Collins, J. A., Hagan, B. T., Bratt, H. M., (1976). The failure-experience matrix-A useful design tool, *Transactions of the ASME, Series B, Journal of Engineering in Industry,* vol.98, Aug; 1074-1079.

Colquhoun, G. J. et al. (1991). A generic IDEF0 model of process planning.

International journal of production research, 29 (1991), 2239-2257.

Cooper, R. Kaplan, R.S. (1991). *The design of cost management systems; text, cases and readings,* New Jersey, Prentice-Hall Inc.

Cooper, Robin et al. (1997). Target costing and value engineering. Productivity Press, Portland, Oregon.

Court, A.W. (1997). The relationship between information and personal knowledge in new product development. In: *International journal of information management.* 17(2), 123-138.

Court, A. W., Culley, S. J. and McMahon, C A, (1993). The Information Requirements of Engineering Designers. In: *Proc. 9th Int. Conf. on Engineering Design (ICED '93),* The Hague, 17-19 August 1993,1708-1716.

Court, A W, Culley, S J and McMahon, C A (1995) Modelling the Information Access Methods of Engineering Designers. In: *Proc 7th Int. Conf. Design Theory and Methodology,* (ed A C Ward), held as part of the ASME Design Engineering Technical Conferences, Boston, Ma, 17-21 September 1995, DE-Vol 83, Volume 2, 547-554.

Creasy, R., (1973). *Functional Analysis System Technique Manual,* Society of American Value Engineers, Irving.

Dieter, G. E. (1983). *Engineering Design: a Materials and Processing Approach.* Tokyo: McGraw-Hill.

Dorador, J.M. and Young, R.I.M. (2000). Application of IDEF0, IDEF3 and UML methodologies in the creation of information models. In: *International journal of computer integrated manufacturing,* 13(5), 430-445.

Drucker, F. P. (1969). *The age of discontinuity: guidelines to our changing society.* Heinemann, London.

Duverlie, P. et al. (1999). Cost estimation during design step: parametric versus case based reasoning method. In: *International journal of advanced manufacturing technology,* 15(12), 895-906.

Elias, Samy E.G. (1998). Value engineering, a powerful productivity tool. In: *Computers and industrial engineering*, 35(3-4), 381-393.

Ericsson, Karl et al. (1984). *Protocol analysis: verbal reports as data.* MIT Press, USA.

Eriksson, H., E. and Penker, M. (2000). *Business modelling with UML: business patterns at work.* Wiley, New York.

Evans, D. and Gruba, P. (2002) *How to write a better thesis.* 2nd edition, Melbourne University press, Australia

Farineau, T. et al. (2001). Use of parametric models in an economic evaluation step during the design phase. In: *International journal of advanced manufacturing technology*, 17 (2001), 79-86.

Feng, J. (1998). Concepts for Modelling Information Formally. *In: Matching Technology with Organisational Needs, Proc. of 3rd UKAIS Conference.* Avision, D. and Edgar-Nevill, D. ed., McGraw-Hill, Maidenhead in England.

Flyvbjerg, B. "Five Misunderstandings About Case Study Research". *In: Qualitative Inquiry*, vol. 12, no. 2, April 2006, pp. 219-245

Ford Motor Company (2001), *The Ford Story.* Company Information, http://www.ford.com/servlet/ecmcs/ford/index.jsp?SECTION=ourCompany&LEVEL2=heritage&LEVEL3=theFordStory, (Accessed 10 June 2001).

Fowler, M. (2000). *UML distilled*, 2nd ed. Addison Wesley, London.

French, M. J. (1999). *Conceptual design for engineers*, 3rd ed. Springer, London.

Galorath Incorporated (2002). SEER tools. *Citing Internet resources* (WWW document). www.galorath.com (Accessed 1st June, 2002).

Geiger, T.S. et al. (1996). Automated design-to-cost: integrating costing into the design decision. In: *Computer-aided design*, 28(6/7), 423-438.

Grundy, Tony (1996). Cost is a strategic issue. In: *Long range planning*, 29(1), 58

Gummersson, E. (1991). *Qualitative methods in management research,* Newbury Park Publications, California, USA.

Gunasekaran, A. and Sarhadi, M. (1998). Implementation of activity-based costing in manufacturing. In: *International journal of production economics,* 56-57 (1998), 231-242.

Hares, John S. (1994). *SSADM version 4: the advanced practitioner's guide.* Wiley, Chichester.

Howe, D. (2000). *Aircraft conceptual design synthesis.* Professional Engineering Publication, London, UK.

Hubka, V., (1980). Principles of Engineering Design ", (translated by W.E. Eder), Butterworth Scientific, London.

Humphreys, Kenneth et al. (1996). *Basic cost engineering.* 3rd rev ed. Marcel Dekker, New York.

Hughes, Robert T. (1996). Expert judgement as an estimating method. In: *Information and software technology,* 38 (1996), 67-75.

Hyder, Akmal S. et al. (1999). Accounting as a management tool for non-industrial private forestry. In: *Scandinavian journal of management,* 15(2), 173-191.

ICEC (2002). *About Standardisation.* http://www.icoste.org, (Accessed June 2002)

Innes, John et al. (1994). *Activity costing for engineers.* John Wiley, New York.

Iwasaki, Y. M., Vescovi, R. F. and Chandrasekaran, B. (1995). Casual functional representation language with behaviour-based semantics. In: *Applied Artificial Intelligence,* 9:5-31.

IDEF (2002). A structured approach to enterprise modelling and analysis. *Citing Internet resources* (WWW document). www.idef.com (Accessed 31st October, 2002).

Jacobson, Ivar et al. (1999). *The unified software development process*. Addison-Wesley, London.

Johnson, H. T. and Sapp, R. W. (1992). Memo to global competitors: it is time to replace cost accounting with process based information. In *Economics of Advanced Manufacturing Systems,* ed. H. R. Parsei & A. Mital, London: Chapman & Hall: 179-188.

Kato, Yutaka (1993). Target costing support systems: lessons from leading Japanese companies. In: *Management accounting research,* 4(1), 33-47.

KBSI. (2001). ProSim 6, http://www.kbsi.com/Software.htm. (Accessed June 2001)

Kimura F. et al. (1995). Representing Background Information for Product Description to Support Product Development Process. In: *The Annals of the CIRP,* Vol.44 (1), 113-116

Kingsman, Brian G. et al. (1997). A knowledge-based decision support system for cost estimation and pricing decisions in versatile manufacturing companies. In: *International journal of production economics*, 53 (1997), 119-139.

Kirschman, C. and Fadel, G. (1998). Classifying functions for mechanical design. In: *Journal of Mechanical Design, Transactions of the ASME*, vol. 120(3):475-482.

Kloock, Josef et al. (1997). Marginal costing: cost budgeting and cost variance analysis. In: *Management accounting research*, 8(3), 299-323.

Koponen, Harri (2002). *The development of an information infrastructure for cost estimating in the automotive industry*. MA Thesis, Cranfield University, Bedford, UK.

Kulmala, Harri I. et al. (2002). The role of cost management in network relationships. In: *International journal of production economics*, 79(1), 33-43.

Lai, K. and Wilson, W. (1989). FDL-A language for functional description and rationalization in Mechanical Design. In: *Journal of Mechanics, Transmissions, and Automation in Design*, vol. 111, 117-123.

Lederer, Albert L. (1995). Causes of inaccurate software development cost estimates. In: *Journal of systems software*, 31 (1995), 125-134.

Liebers A. (1998). *An architecture for cost control, the use of cost information in order-related decisions,* Ph.D. thesis, University of Twente, Enschede, The Netherlands.

Locascio, Angela (2000). Manufacturing cost modelling for product design. In: *International journal of flexible manufacturing systems*, 12 (2000), 207-217.

Lucas, Henry (1997). *Information technology for management,* 6th ed. McGraw Hill, New York.

Loos, Peter (1998). Object-orientation in business process modeling through applying event driven process chains (EPC) in UML. In: *Second international enterprise distributed object computing workshop*, EDOC '98, 1998. Proceedings, 102 -112.

Love, S. F. (1986). *Planning and Creating Successful Engineering Designs.* Advanced Professional Development Incorporated, North Hollywood, Ca., 1986.

Lutters, D., Streppel, A.H., Kals, H.J.J., (1997). The role of information structures in design and engineering processes. In: *Proceedings of the third WDK workshop on product structuring,* Delft, 125-136.

Luo, Wenhong (1999). A framework for selecting business process modeling methods. In: *Industrial management and data systems*, 99(7-8), 312-319.

Maisel, L. and Morrissey, E. (1993). Using Activity-Based Costing to Improve Performance. In *Handbook of Cost Management, 1994 Edition* (edit. B. J. Brinker). Boston: Warren Gorham Lamont.

Matveev, V. A. (2002). The advantages of employing quantitative and qualitative methods in intercultural research: Practical implications from the study of the perceptions of intercultural communication competence by American and Russian managers. *In: Collected research articles, Bulletin of Russian Communication Association "THEORY OF COMMUNICATION AND APPLIED*

COMMUNICATION", Issue 1, Institute of Management, Business and Law Publishing, 2002. - 168 p. P. 59-67, New York, USA

Mayer, Richard J. et al. (1995). Information integration for concurrent engineering (IICE) IDEF3 process description capture method report, September 1995. *Knowledge Based Systems, Inc. Citing Internet resource* (PDF document). http://www.idef.com/Downloads/pdf/Idef3_fn.pdf. (accessed 8th August 2002).

Melao, Nuno et al. (2000). A conceptual framework for understanding business processes and business process modelling. In: *Information systems journal*, 10(2), 105-129.

Mileham *et al.* (1993). A Parametric Approach to Cost Estimating at Conceptual Stage of Design. In: *Journal of Engineering Design.* Vol.4, (2), 117-125.

Mo, John et al. (1998). An integrated process model driven knowledge based system for remote customer support. In: *Computer in industry*, 37 (1998), 171-183.

Mukherjee, M. et al. (1997). Conceptual Design, Manufacturability Evaluation and Preliminary Process Planning Using Function-Form Relationships in Stamped Material Parts. In: *Robotics and Computer Integrated Manufacturing.* Vol.13 (3), 253-270.

Niu, M. (1988). *Airframe structural design: practical design information and data on aircraft structures*, Conmilit, Hong Kong.

Oppenheim, Abraham (1993). *Questionnaire design and attitude measurement,* 2nd edition. Pinter, London.

Ou-Yang, C., Lin, T.S. (1997). Developing an integrated framework for feature-based early manufacturing cost estimation, In: *International Journal of Advanced Manufacturing Technology* 13/9, 618-629.

Pahl, G. and Beitz, W. (1988). *'Engineering Design: A Systematic Approach'*, Springer Verlag.

Patton, M.Q. (1980). *Qualitative evaluation methods.* Newbury Park, CA: Sage

Perera, Srinath et al. (1998). Collaborative case-based estimating and design. In: *Advances in engineering software*, 29(10), 801-808.

Phillips, M. P. and Pugh, S. D. (2000) *How to get a PhD: A handbook for students and their supervisors.* 3rd edition, Open University, Buckingham, UK

Prall J. R and Zecher E., (2001). Cost Engineering, September 2001 issue, AACE publication.

Price Systems (2002). PRICE H, the Hardware Estimating Model. *Citing Internet resources* (WWW document). www.pricesystems.com (Accessed 31st October, 2002).

ProSim, (2002), http://www.prosim.net/english.html (Accesses 1st June 2004)

Pugh Stuart (1990). Variations to the Total Design Activity Model. In: *Total Design*. Addison-Wesley Publishing Company

Pugh, P. (1992). Working Top-Down: Cost Estimating Before Development Begins. In: *Journal of Aerospace Engineering*, Part G, Vol.206, 143-151

Rehman, S. and Guenov, M.D. (1998). A methodology for modelling manufacturing costs at conceptual design. In: *Computers and industrial engineering*, 35(3-4), 623-626.

Robson, C. (2002). *Real world research: a resource for social scientists and practitioner-researchers.* 2nd edition, Blackwell Publishers, Oxford, UK.

Roy, R. et al (2001a). Commercial and engineering activities within cost estimating: industry practise AS-IS. ICOST *internal report, ICOST01/April 2001.* Cranfield University.

Roy, R. et al. (2001b). Quantitative and Qualitative Cost Estimating for Engineering Design. In: *Journal of Engineering Design*, Carfax Publishing Taylor & Francis Ltd., vol. 12, number 2, 147-162

Rush, C. (2002), Formalisation and reuse of cost engineering knowledge; PhD thesis, Cranfield University, UK

SAVE, (2001). Publications and product Catalogue, In *SAVE International.* http://www.value-eng.org/, (Accessed June 2001)

Schreiber, G., Akkermans, H., Anjewierden, A. (2000). *Knowledge Engineering and Management: The CommonKADS Methodology.* MIT Press, Cambridge, USA.

Shehab, E.M. et al. (2001). Manufacturing cost modelling for concurrent product development. In: *Robotics and computer-integrated manufacturing*, 17, 341-353

Shepperd, M. et al. (1997). Estimating software project effort using analogies. In: *IEEE Transactions on software engineering*, 23(12), 736-743.

Shuford, R.H. (1995). Activity-based costing and traditional cost allocation structures. In: R.D. Stewart, R.M. Wyskida, J.D. Johannes (eds.), *Cost estimator's reference manual,* 2nd ed., New York, Johan Wiley & sons Inc, 41-94

Smith M.J. (1988). *Contemporary communication research methods.* Belmont, CA: Wadsworth, Inc.

Stamelos, Ioannis (2001). Managing uncertainty in project portfolio cost estimation. In: *Information and software technology*, 43, 759-768.

Stewart, 1995a R.D. Stewart, R.M. Wyskida, J.D. Johannes (eds.), *Cost estimator's reference manual,* 2nd ed., Johan Wiley & sons, inc, New York.

Stewart, 1995b R.D. Stewart, 'Detailed cost estimating', In: R.D. Stewart, R.M. Wyskida, J.D. Johannes (eds.), *Cost estimator's reference manual,* 2nd ed., New York, Johan Wiley & sons Inc, 193-231.

Sturges, R. H., et al. (1993). A systematic approach to conceptual design. In: *Concurrent Engineering: Research and Application,* 1:93-105.

Nam Suh (1990). *The Principles of Design.* Oxford Series on Advanced Manufacturing.

Tessem, B. et al. (1997). Analogy and complex software modelling. In: Computers in human behaviour, 13(4), 465-486.

Theodoracatos, V. E. *et al.* (1994) ECDEX: A Knowledge-based approach to conceptual design of engineering systems. Ro*botics and Computer-Integrated Manufacturing.* Vol.11 (3). 137-166.

Thompson, F. (1998) 'Cost Analysis', *Unpublished paper,* Fellow Willamette University, http://www.willamette.edu/~fthompso/.

Tomiyama *et al.* (1993). A CAD for Functional Design. *The Annals of the CIRP.* Vol.42 (1). 143-146.

Toffler, Alvin (1980). The third wave. Collins, London.

Ullman, D. (1997). *The mechanical design process.* McGraw-Hill, New York, USA.

Vernadat, Francois (1996). Enterprise modelling and integration: principles and applications. Chapman and Hall, London.

Vitaliano, William J. (1994). Three design to cost myths. In: 1994 International conference of the society of American value engineers (SAVE), New Orleans, USA. SAVE annual proceedings.

Weustink, 2000 I.F. Weustink, E. ten Brinke, A.H. Streppel, H.J.J. Kals, 'A generic framework for cost estimation and cost control in product design', *Journal of Materials Processing Technology* 103, 141-148.

Whitaker, L.A. et al. (1989). Bidder's Associate: a case-based reasoning system to improve cost estimates of manufactured products. In: IEEE international conference on systems, man and cybernetics, Conference Proceedings, volume 2, 521 -522.

Williamson, Duncan (1996). Cost and management accounting. Prentice Hall Europe, London.

Wierda L.S. (1990), *Cost information tools for designers, a survey of problems and possibilities with an emphasis on mass produced sheetmetal parts,* Ph.D. thesis, University of Delft, Delft, The Netherlands.

Wierda, L.S. (1991) 'Linking design, process planning and cost information by feature-based modelling', *Journal of Engineering Design* 2/1, 3-19

Williamson, Bill (1994). Design to cost lessons learned. In: 1994 International conference of the society of American value engineers (SAVE), New Orleans, USA. SAVE annual proceedings.

Wu, B. (1994). Manufacturing systems design and analysis: context and techniques, 2nd ed. Chapman and Hall, London.

XR-Associates (2001), *About XR Associates*. Corporate Profile, http://www.xr-associates.co.uk/corp.html, (Accessed June 2001)

Yin, R. (1994). *Case study research design and methods*. Beverly Hills, CA: Sage Publications Inc. USA.

Yoshikawa, T. et al. (1994), *'Applying functional cost analysis in a manufacturing environment"*, International Journal of Production Economics, vol.36, 53-64.

Zhang, Jian (1996a). Information modelling for manufacturing systems: a case study. Robotics and computer-integrated manufacturing, 12(3), 217-225.

Zhang, Y.F. (1996b). Feature-based cost estimation for packaging products using neural networks. Computers in industry, 32 (1996), 95-113.

Zhao, J. et al. (1999). A consistent manufacturing data model to support virtual enterprises. International journal of agile management systems, 1/3, 150-158

Zucker, J. et al. (1995). Extensible organization of property descriptions in object modelling for engineering design. Knowledge-based systems, 8(5), 279-290.

Appendix A

AS-IS Questionnaire

ICOST Industrial Questionnaire:

AS-IS Model of the Interface Between Cost Estimating & Cost Engineering Processes

Developing An Integrated Costing Approach
For Conceptual Design Evaluation
ICOST
Project Duration: 2000-2003

Rajkumar Roy,
Petros Souchoroukov, Keren Mishra

Department of Enterprise Integration,
School of Industrial and Manufacturing Science,
Cranfield University, Cranfield,
Bedfordshire, MK43 OAL, UK.
Tel:+44 (0) 1234 754073, Fax: +44 (0) 1234 750852
Email:{ r.roy, p.souchoroukov, k.mishra }@cranfield.ac.uk,

Name: ....

Title: ....

Organisation: ....

Department: ....

Address: ....

....

Telephone Number: ....

Fax Number: ....

Email: ....

The information provided will be held in the strictest of confidence, desensitised, and used for academic and research purposes ONLY.

Interview conducted by: ....

Introduction

The research attempts to integrate commercial cost estimating with technical cost engineering by developing an innovative and generic approach to costing. The approach addresses two major issues: the people issue and technical issues behind the costing. The concept of integration (between the commercial and technical costing activities) is very novel, with no work being reported exactly in this area. The research will improve communication between the cost estimators and cost engineers. The outcome of the proposed research will make the cost estimation process more transparent and accurate, and thus will assist in designing a product 'right first time'.

Definition of Cost Estimating & Cost Engineering

Manufacturing industry performs cost estimating throughout the life cycle of a product. The purpose of commercial cost estimating is to provide key business information for decision making in a top-down fashion. This costing discipline tries to evaluate, and optimise a combination of requirements (customer and business) with potential or selected solution(s), across a wide range of business processes, with cost as the common denominator. Alternatively, the Cost Engineering discipline tries to model the design to manufacturing cost in a bottom-up approach for establishing relative costs for different solutions, and methods. Similarly, the cost engineering discipline needs to have detailed knowledge about the product, the manufacturing process, and manufacturing capability of the organisation. But unlike cost estimating, cost engineering discipline focuses on design, manufacturing, and tooling activities only. They also need to be fully aware of UK & customer government legislative regulations, which govern justification and access to data used in the estimating process.

Due to this mismatch of focus, and differences in terminology and level of detail, there is a gap between the two disciplines, and this leads to inconsistencies in costing practices. There is also a lack of knowledge about each other's activities. Both cost estimating and cost engineering are essential during the conceptual product development stage for design evaluation, and thus optimisation.

Purpose of the Questionnaire

The two costing disciplines that work towards overall costing of a product are Commercial cost estimating and Technical cost engineering: It has become apparent that at present these practices are not utilising their full potential of creating an efficient estimate, right from the early stages of product development. This is due to poor internal communication – actually between the costing disciplines.

In order to improve this current state of costing affairs, Questions and Interviews are necessary to establish current practice within industry; and to also determine what type of interaction is currently occurring between the two costing disciplines.

Once these internal processes have been acquired –through the questions /interviews, ICOST can then proceed to expose any weak links present between these practices, including lack of communication and comprehension of each prospective discipline, and thus proceed to establish firm, consistent method of costing across industry.

Overall Aim: How Is An Estimate Produced?

*Please note: Questions asking about the practices of an **'estimator'** or **'estimate'**, should be answered according to your own profession,*

i.e. ***Commercial cost Estimator***

(those covering commercial areas -financial, etc,);

Technical cost Engineers *(for those working in engineering, software, etc)*

Module 1 (General Issues)

Q1: How long have you been employed in the company?

Q2: What is your role in the company?

Q3: How long have you held this position?

Q4: What is your experience (Academic & Industrial) prior to your current position?

Q5: How much input to an estimate is via experience / expertise of estimator?
(with respect to both commercial and technical estimates)

Module 2 (Interface)

Q1: Could you explain the absolute fundamental development stage(s) of creating an estimate?

Q2: What level of contribution towards the estimate comes from other departments?

Q3: Which individual departments are involved in creating an estimate?

Q3a: What is the input of these departments?

Q4: Is the data/product information that is required from other departments

Q4a: Easily procured?

Q4b: comprehensible to the recipient?

Q4c: How is it communicated? *(meetings, reports, email / Intranet etc)*

Q4: How is all relevant information linked?

Q5: How is your role different to those of the other contributors toward an estimate?

Q6: How are these roles similar? And how/in what areas do they overlap?

Appendix B

Data & Information Questionnaire

QUESTIONNAIRE

A. Background

Q1: How long have you been employed in the company?
Q2: What is your role in the company?
Q3: How long have you held this position?
Q4: What is your experience (academic and industrial) prior to your current position?

B. Costing Process

Q1: Could you explain the fundamental development stage(s) of creating an estimate?
Q2: What different cost estimation techniques are used?
Q3: What type of information is used to create cost estimates during different stages?
Q4: What information do you feel you require that is currently not provided?
Q5: What type of cost models and costing data templates are used?
Q6: What established practices are used for costing data collection?
Q7: Are there established practices for using the cost information?

C. Cost Information I

Q1: How do you categorise cost information into different classes?
Q2: How much input to a cost estimate is
a) based on experience?
b) acquired through personal communication?
c) defined in specifications?
d) derived from drawings/designs?
e) resides in databases, especially for cost estimation purposes?
f) extracted from existing parts or components?
g) found from other sources?
Q3: What types of Assumptions and Exclusions are made during estimation?
Q4: How do outsourced parts change information needs compared to in-house production?

D. Cost Information II

In this section the above elicited cost categories and cost information will be analysed individually. Please use the empty sheets at the end of the questionnaire to provide your responses.

Q1. Where is this information found?
Q2. How is it accessed?
Q3. Why is this information needed?
Q4. When (during the cost estimation process) is this information needed?
Q5. In what format is the information?
Q6. How often is this information updated?
Q7. How is this information validated?
Q8. How is this information normalised?

Appendix C

Costing Processes

Detailed Bottom up Costing Process

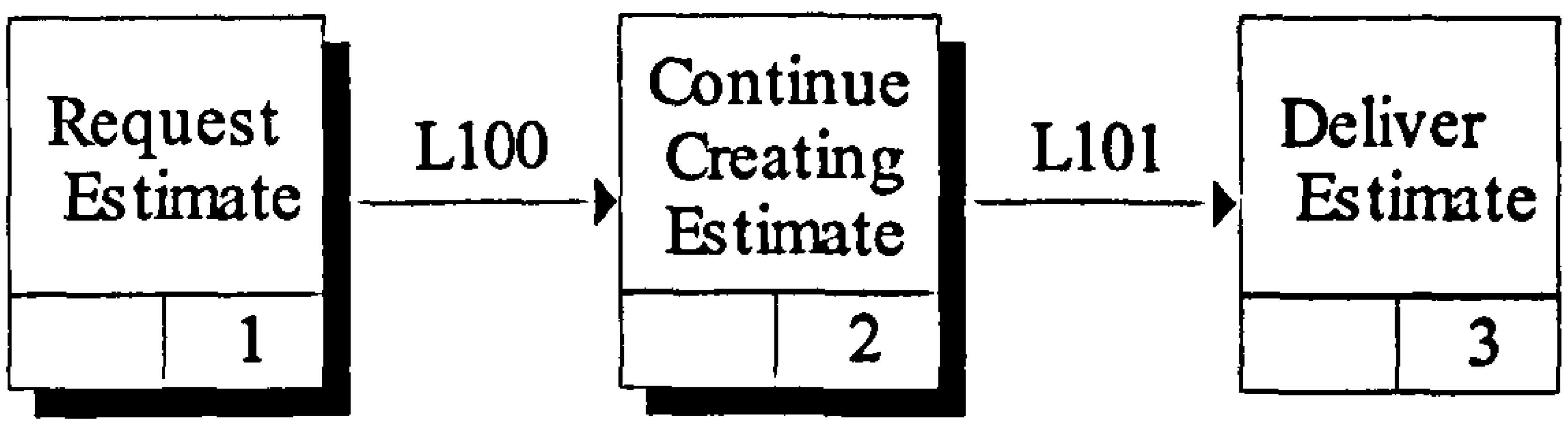


Figure 1 "Overview of cost estimating function

In figure 1, the primary function of the cost-estimating department is represented in a top-down function. On the bottom right of each box a number can be identified that represents the current level of detail. For example, if we were to follow level 1 further, to create more detail, the numbering would be as follows: 1.1, 1.2, and 1.3. If we were going to go into even greater detail of 1.1 then the numbering would become 1.1.1, 1.1.2, 1.1.3, etc.

All the requests to the cost-estimating department result into the preparation of detailed estimate. There are different departments that request different levels of detailed estimates and information from the cost estimators.

1.2 Service to Purchase

On request, the Cost Estimators provide detailed piece cost estimates to support Purchasing in negotiations with suppliers. This can be in support of ongoing cost reduction initiatives or alternative sourcing opportunities. Cost Estimators also perform Tooling Order Value-for-Money checks on all vendor-tooling orders over US$ 25,000.

1.3 Cost Requests

Cost Estimators are requested to establish detailed, bottom up estimates when supplier quotes are over target, when no target has been established or in cases where no quote is available. Estimates need to be fully processed and will be used in technical discussions with suppliers. Estimates are required for piece cost and vendor tooling costs.

1.4 Commodity Cost Reduction Teams (CCRTs)

CCRTs conduct a focused, 90 day, cross carline cost reduction effort on a particular commodity. The objective is to achieve Design and Commercial competitiveness (Benchmark status) without feature deletion or risk to quality. Commercial competitiveness is normally assessed through Gap to Benchmark analysis; Design competitiveness through Ford/ Competitor teardown or CAB (Competitor Analysis Benchmark) reviews. The core teams consist of Supplier, Product

Development (PD), Purchase and Cost Estimating (CE) representatives and are supported by Finance, Manufacturing, Freight and Logistics specialists, etc.
CE-E will normally provide zero based, variance or feature adjusted Market Price estimates for use by the purchase to support fact based gap closure negotiations. In addition, estimators will assess the cost impact of design proposals or modifications in support of establishing the Business equation of the various Design proposals developed by the teams. CE-E are also great contributors in terms of suggesting alternative design/ commercial proposals at Team workshops.

1.5 Value Management

Cost Estimators support Value Benchmarking exercises of Competitors and in-house products to assist in establishing Targets. They attend and support Value Engineering workshops to assist teams in identifying value improvements for Target achievement. Value Analysis workshops are also supported to identify cost reduction opportunities for present models.

1.6 PVT (Product Vehicle Team)

PVT's are located at lead manufacturing plants. They are fully responsible for all running changes, small programs, special value programs, cost reduction programs and quality actions following Job#1 release at the manufacturing plant and for the next three months, through to the end of the life of the carline. These teams stay in place until a new launch team is established for the successor of that carline. Cost Estimators are full time, co-located team members for vehicle PVT's and represent Cost Estimating in all supplier-related actions and issues. Powertrain Cost Estimators provide similar support through the Change Control process, as Powertrain plants do not operate the PVT process.

1.7 Launch Team

Cost Estimators are full time, co-located members of the Launch Teams for all major vehicle programs. Powertrain Cost Estimators also support launch teams but are generally not co-located. Cost Estimators are responsible for verifying supplier quotations and providing estimating support for piece cost and vendor tooling costs in line with design assumptions from engineers. The turnaround time for costing requests is 48 hours in the Launch Team, reducing as Job#1 approaches.

1.8 Change Control

Change Control is conducted through a Concern Driven Transmittal process that is handled within the PMT's (Product Management Team). To support this process, Cost Estimators provide a cost evaluation service to engineers.

1.9 PMT

Cost Estimators are full time members of the PMT's which are established to support each major program. In these meetings, estimators are responsible for verifying supplier quotations and providing estimating support for piece costs and vendor tooling costs in line with design assumptions from engineers.

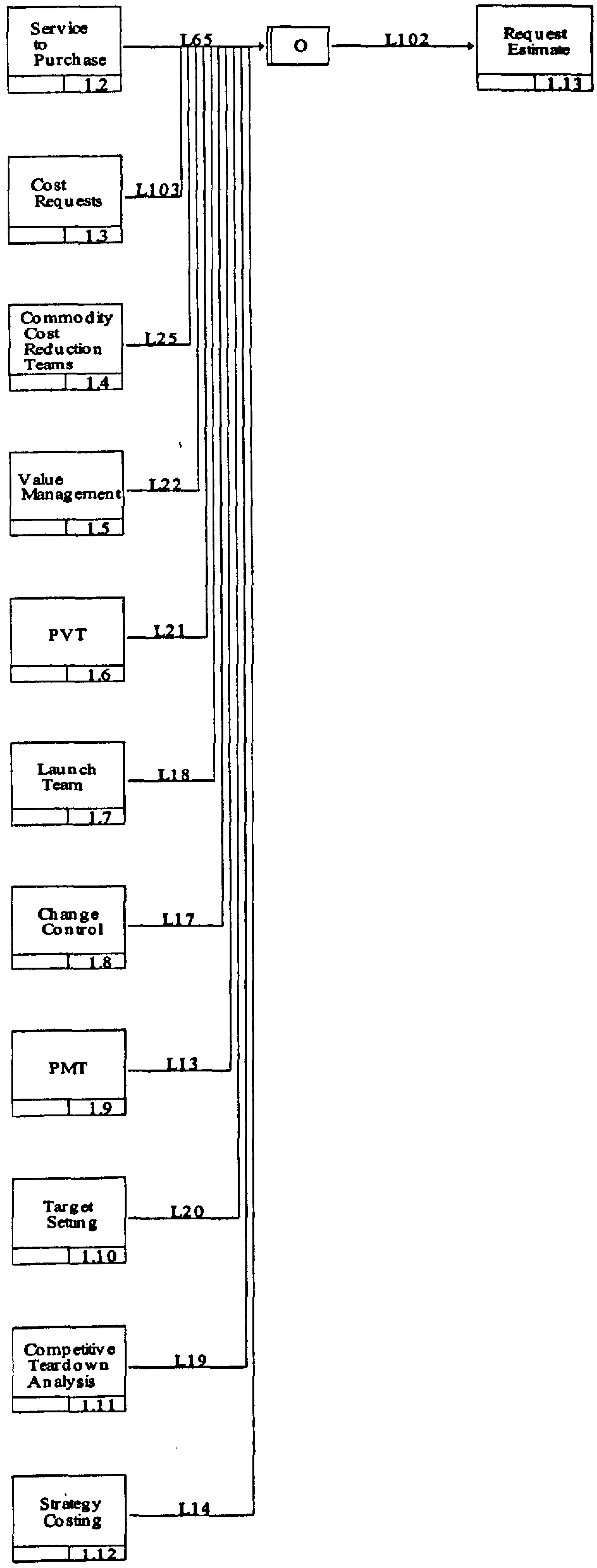


Figure 2 "Decomposition of inputs"

1.10 Target Setting

Cost Estimators are members of new model Target Setting teams. After evaluation of the Affordable Cost Target, Cost Estimators are requested to support Target Agreement meetings to establish, together with the supplier, the buyer and the engineer, a roadmap for target achievement. Cost Estimators need to understand supplier's production processes and propose cost reductions.

1.11 Competitive Teardown Analysis

Cost Estimators are members of new model Target Setting teams. After evaluation of the Affordable Cost Target, Cost Estimators are requested to support Target Agreement meetings to establish, together with the supplier, the buyer and the engineer, a roadmap for target achievement. Cost Estimators need to understand supplier's production processes and propose cost reductions.

1.12 Strategy Costing

To support early Program Definition, vendor-tooling costs are established by Cost Estimating based upon early Features Lists or design assumptions. In addition, design alternatives are investigated. This requires general engineering skills and experience in latest manufacturing techniques and processes.

2.1 Receive Specifications

When the product development is at its earliest stages, the Product Development Team produces a specification list for the Cost Estimator, to be able to produce a first estimate. These are usually the tooling costs, since the estimator does not have detailed information about the actual part. The data provided for this activity is the BOM (Bill of Material) and a feature list of the product.

2.2 Receive Part

In a lot of cases, when the Estimator is requested to produce a cost estimate, he will be provided with only the actual part. In this case, the estimator will try to extract as much information as possible to perform the estimate. This will provide the cost estimator with the dimensions and the weight of the part.

2.3 Receive Design

In this case, the estimator has access to the actual design and the specifications of the part (printed on the design). This is the maximum information that can be available to the estimator in one process step. By having the design he can find out any design assumption made of design alternatives that the engineer is suggesting.

2.4 Apply Expertise

The cost estimator using his expertise is able to see if he has all the relevant information to prepare the estimate. If the Information available is not sufficient, he'll try to acquire it.

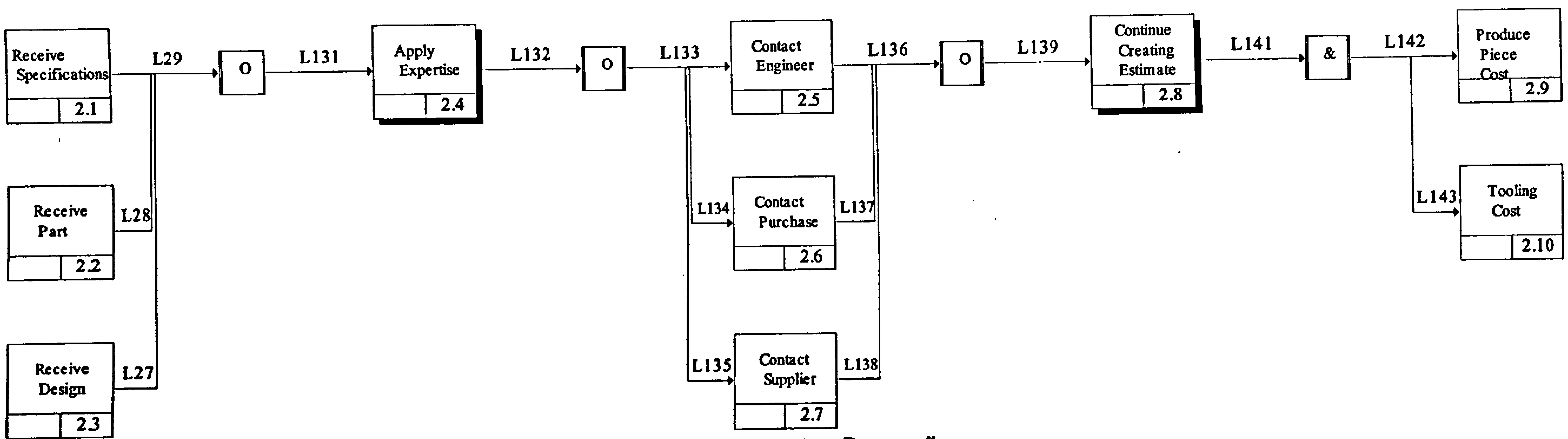


Figure3 "Cost Estimating Process"

2.5 Contact Engineer

By contacting the engineer, the cost estimator is able to get more information, e.g. why the change was done and how. Also the engineer, as the 'system owner', will also know what has been involved (e.g. new parts put in, old parts taken out). The same thing will be done with the Manufacturing Process (fitting of the part). Again, a centre of competence (departments or people that are experts within a specific field) will be involved for each area.

2.6 Contact Purchase

A lot of the time, purchasing has information before it reaches the engineering department since this is the department that will be contacted in case of a change.

2.7 Contact Supplier

Since most of the time suppliers design and make a part, it's more likely that they'll have some extra information available (e.g. capabilities of their machines).
They will be able to provide them with what they need (changes and processes).

2.8 Continue Creating Estimate

After all the necessary information is collected, the estimator will continue with creating his estimate.

2.9 Produce Piece Cost

The cost of producing the part is estimated and mark-ups are added. Tooling costs are presented separately.

2.10 Produce Tooling Cost

The tooling costs are calculated for the construction of the parts.

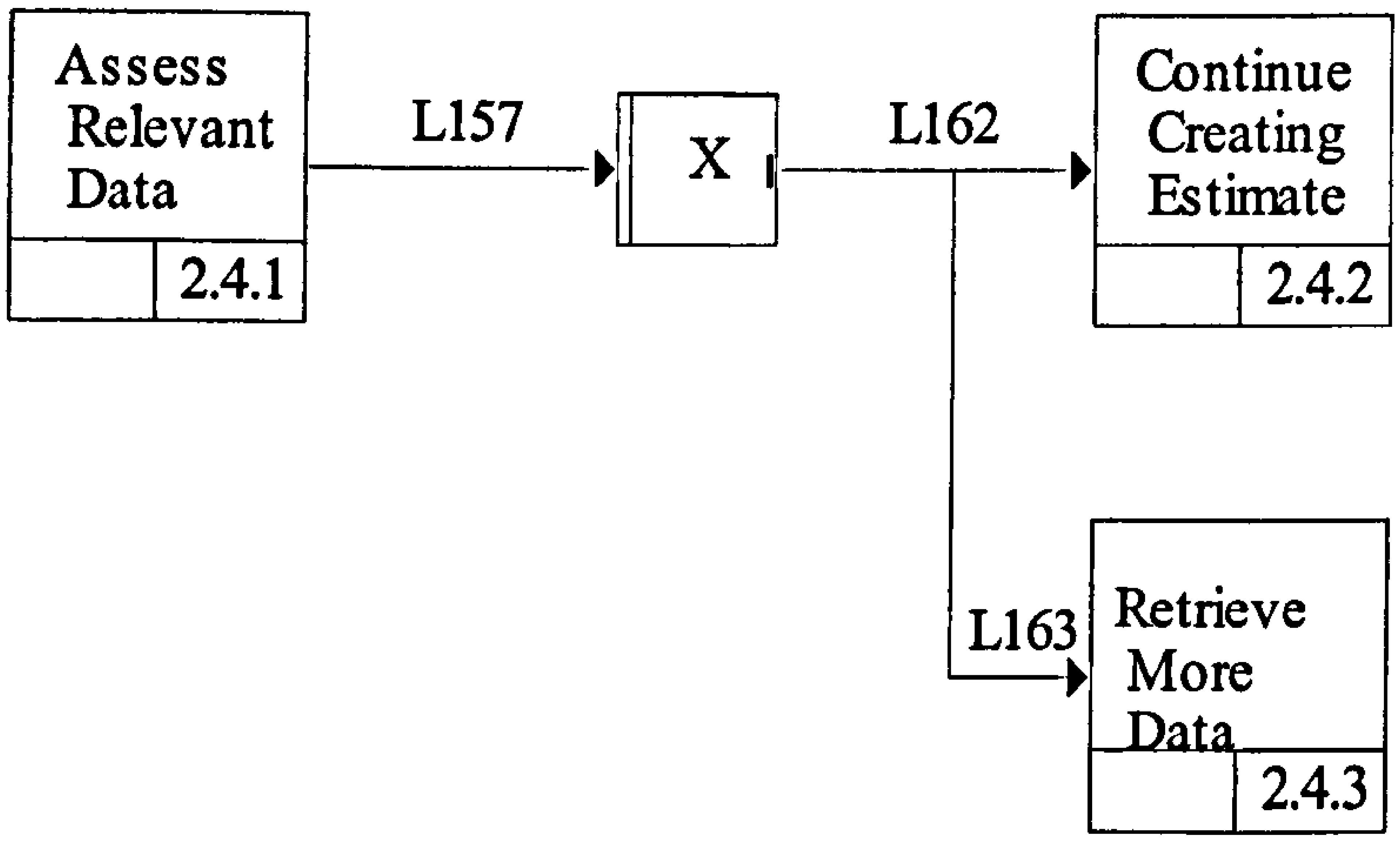


Figure 4 Decomposition of "Apply Expertise"

2.4.1 Assess Relevant Data

The Cost Estimator using his expertise, will decide whether the information available is sufficient or needs to retrieve more data in order to continue with the cost estimate.

2.4.2 Continue Creating Estimate

This refers to the same process as 2.8

2.4.3 Retrieve More Data

The Cost Estimator will try and retrieve more data from the company. The part to be assessed is procured from an engineer or buyer. The buyer will have acquired this part from the original supplier. The information a cost estimator requires from the buyer will be concerned with where the part is from. This will allow all manner of necessary information to be accessed as and when required. In order to gain this information, the estimator would liaise with the buyer; or go directly to the supplier. For both of the previously mentioned contacts for part information, the CE would initially interact via the manager. However when they have had previous dealings, the CE may go directly to the source.

So, the CEs will build a list of contacts within the buyers, suppliers etc. This type of interaction shows that personal relation and contacts are a valuable resource of the cost estimating process. This activity, of building personal contacts and profession relationships can be seen as a commercial activity when performed by a cost estimator.

If the estimator does not have prior information about contacts, the company has a list of personnel which provides a first point of contact. It lists supervisors; names of specialists; where they work; estimating codes; and a contact number.

It does not list the individual commodity that each estimator is responsible for e.g. For each system - the contact person responsible. If the estimator requires further information, they can refer to a worldwide international purchase system available to the company.

An estimator inputs the part code (Each part has a number on it's base, which identifies what part it is, and provides certain other information, including what model it is from, whether is diesel or petrol, and so fourth), Then the system will provide who the buyer and the estimator is.

Keeping this system up-to-date is essential. It is also a very lengthy process. The maintenance team needs to ensure that the database is current for the estimator's individual codes (so they will know whom to contact).

2.8.1 Identify Material

The Cost Estimator will try to identify the material which the part will be manufactured out of and try to calculate the weight. That way the estimator identifies the cost of the cost per piece for each part. In most of the cases the material is identified or very easy to be identified.

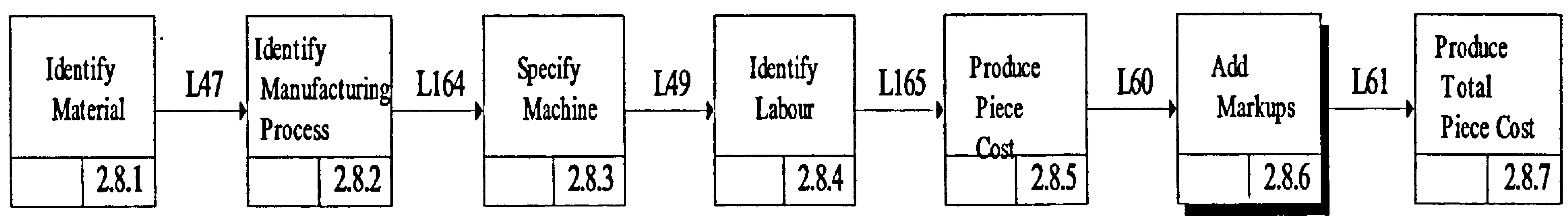


Figure 5 Decomposition of "Continue Creating Estimate"

2.8.2 Identify Manufacturing Process

The cost estimator will identify the best method for creating the product considering quality and cost. The cost engineer has knowledge about most engineering processes necessary for creating automotive parts. By identifying the process, the estimator can now identify the machine.

2.8.3 Specify Machine

This is a very decisive stage in the cost estimating process. Although the cost estimator uses their engineering skills in selecting the process for the manufacturing of a part, the selection of the machine will define the cost. The reason for that is that manufacturing burden costs will be included. Depending on the machine chosen, the costs will be different. The data used for the calculation of the cost will include:

- Lifetime data. The financial life of the machine. The number of years is established by the costing team and is based on information from the machine supplier, user of similar machines and accounting practices.
- Uptime. The time that a machine tool is available for production. This allows for maintenance.
- Floor Cost. This is the cost of 1 square metre of floor space per year. It is made up from the three major categories listed below.

The level of information required to produce accurate cost estimates is enormous. It was decided for this report not to include this information since it was an interim report. However, all the information will be provided for the final report in three months time.

2.8.4 Identify Labour

The cost estimator will decide the skill level required for the operation of the machine and the number of them. In the data available, the labour rate will cover:

- Labour group
- Direct labour
- Indirect labour
- Fringe
- Maintenance Repair & other labour

2.8.5 Produce Piece Cost Estimate

At this stage the estimator has estimated the actual cost of producing the part.

2.8.6 Add Mark-ups .

Mark-ups are applied to the bottom line total of the estimate that includes material, labour and burden. These will be:

- End Item Scrap (2.8.6.1, figure 6)
- Sales General and Administration (2.8.6.2, figure 6)
- Profit (2.8.6.3, figure 6)
- Engineering, Design and Testing (2.8.6.4, figure 6)

2.8.7 Produce Total Piece Cost

This is the final estimate, and it's the only value, with the tooling costs, produced by the cost estimators. This cost estimates are used by various people in different departments for different reasons.

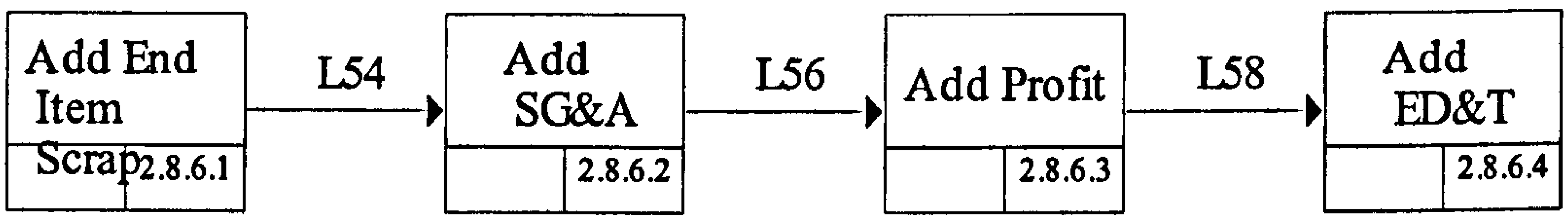


Figure 6: *Mark ups*

Cost Estimating–Other Processes

Other costing processes were observed other than the bottom up approach. A company using the bottom up approach concentrates the effort in creating estimates for current and future vehicles, other processes only concentrated in creating estimates for future models and then monitoring. Furthermore as in the following processes, the data available is much more limited compared to the previous process. There are a lot of different reasons for this. The primary reason is due to the amount of effort put into creating a database. Another major reason is luck of resources. It is a general belief, in the company that a data infrastructure is necessary for performing their cost estimating function better, although they don't think their major role will change in the near future.

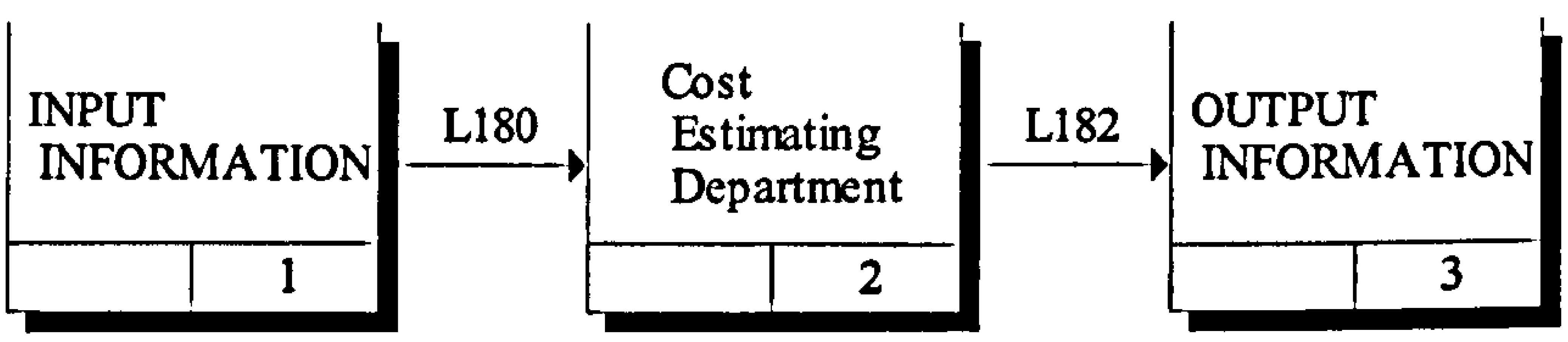


Figure 7 Cost estimating process

Like in the previous section, the processes are categorised as inputs outputs and processes.

1.1 Product Definition

In the early stages of the product, the only description available to cost the new product is the product definition, for example, you want to create a sports car, for two people that can go off-road. By writing just this sentence, you have already created a lot of restriction, and a path is already set for an estimate to be created.

1.2 Market Requirements (CA)

Market requirements are something that has to justify local requirements. E.g. in England a car must have right-steering wheel drive which is different than the rest of the European market. Other example would be that a mirror in US must have a warning sign embedded to it, which is no existent in Europe. All this market requirements have implications in cost. It is also evident that the more different market requirements you have, the more the costs are increased.

1.3 Legal Requirements

With legal requirements we mean the restrictions placed by government laws. E.g. if there is a legal requirement of placing six airbags in all cars, there is a corresponding cost that cannot be avoided, and the cost estimator has to calculate this when his/her performing feature walks.

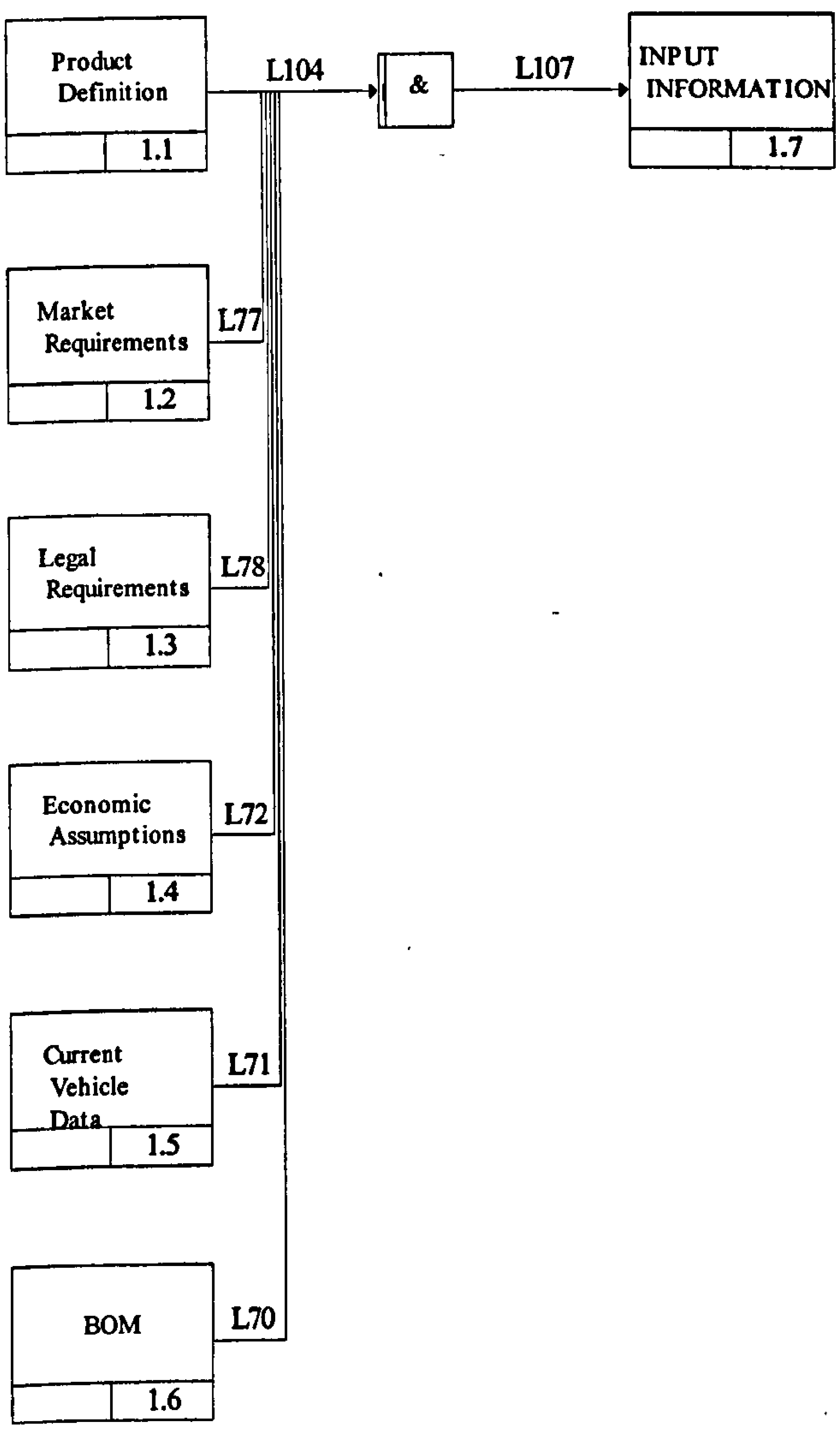


Figure 8 "Cost Estimating Inputs"

1.4 Economic Assumptions

The Economic Assumptions are established from the Project Finance Team. The major elements included in this would be the exchange rates, volume of parts, lifetime, economic restrictions about expenditure (no capital available, low piece cost targets, etc.).

1.5 Current Vehicle Data

The cost estimator tries to utilise as much as possible his historical data that has been collected throughout the years.

1.6 Bill of Materials

The bill of Materials will include every single part and material required to create the component. This is a compulsory data that needs to be provided to the cost-estimating department in order to produce its cost estimates.

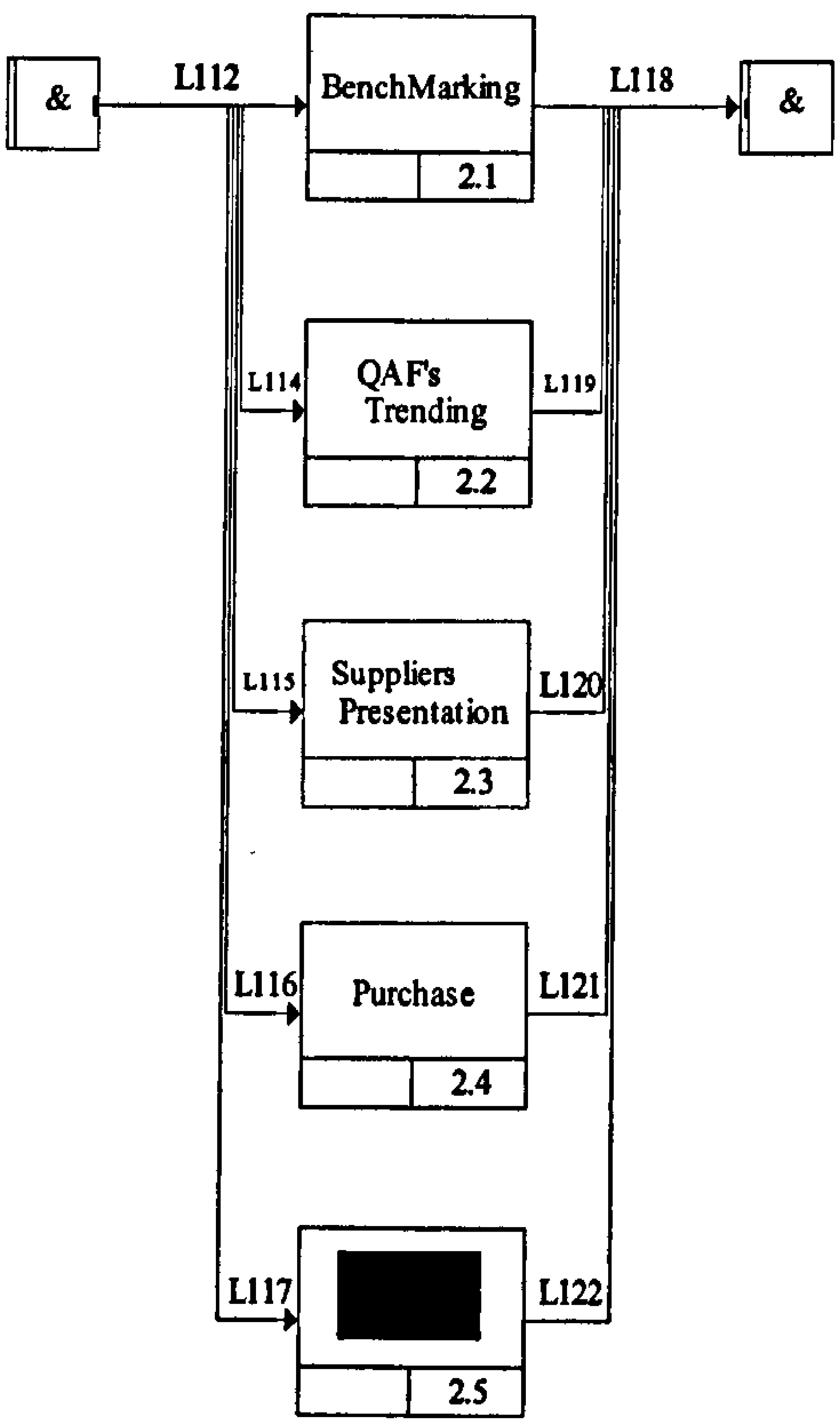


Figure 9 "Cost Estimating Department"

In this diagram, the actual processes that occur in order to create an estimate are presented. A detailed description is provided in the following diagrams.

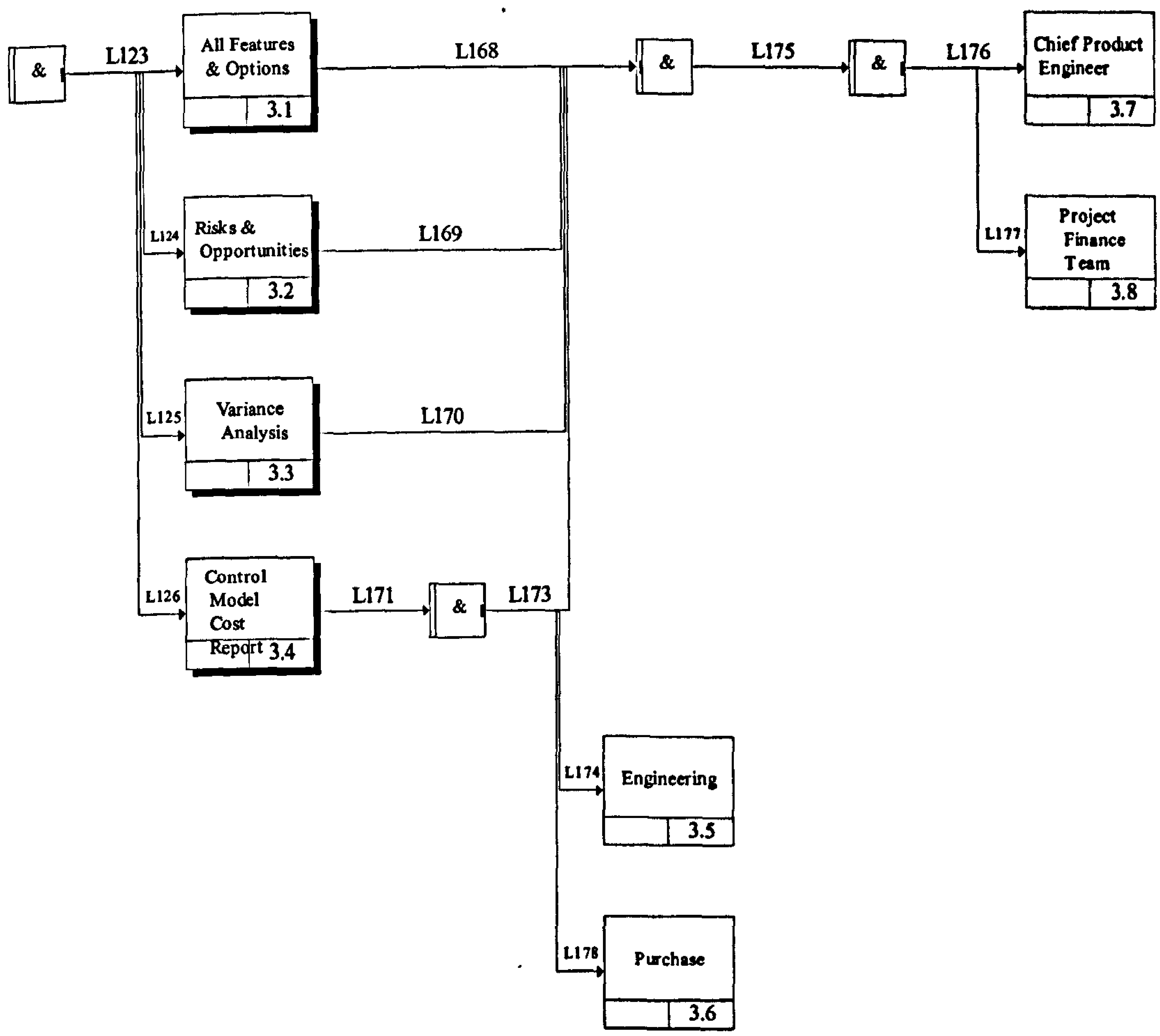


Figure 10 "Cost Estimating Outputs"

3.1 All Features and Options

In this case the Cost Estimators produce Feature Walks. They take the bottom model (the simplest version of the car) and create different specifications vehicle for different markets and countries. This allows the company to see which models are more profitable, so it can build its strategy for the future.

The object used for this output is a features list & option report. It contains all the different models the company is prepared to make.

3.2 Risks and Opportunities

What the CE does in this case is to create different possible variance analysis reports, assuming from his experience, to identify possible difficulties that the product might encounter in the future. That would be in conjunction with the engineering department. E.g. if the engineering department was finding it necessary to include a specific feature that would increase the performance of the car, but it would have meant an increase of costs, then it would have been considered as a risk.

3.3 Variance Analysis

The CE identifies any possible variances between target & status reports.

3.4 Control Model Cost Report

The Control Model Cost Report is probably the biggest contributions of the cost estimator to the car development process. For this output the cost estimator produces Piece costs and tooling costs, in both of which he will further produce a target report and a status report. For the Piece Costs (Target) and the Tooling Costs (Target) he produces estimates-guides of how much the specific piece should cost in the company in order to make the desired profit. For the Piece Costs (Status) and Tooling Costs (status) he produces estimates of where currently the costs are standing.

3.5 Engineering

From the outputs, the engineering department uses the product definition, legal requirements, market requirements and current BOM to create the new BOM.

3.6 Purchase

Purchase will use the information for selecting the future suppliers.

3.7 Chief Product Engineer

He's responsible for the whole project of a specific carline. He is the person who will have to make all the critical decisions in case status and target costs are diverting.

3.8 Project Finance Team

Project Finance uses the data as part of its function to perform cost control

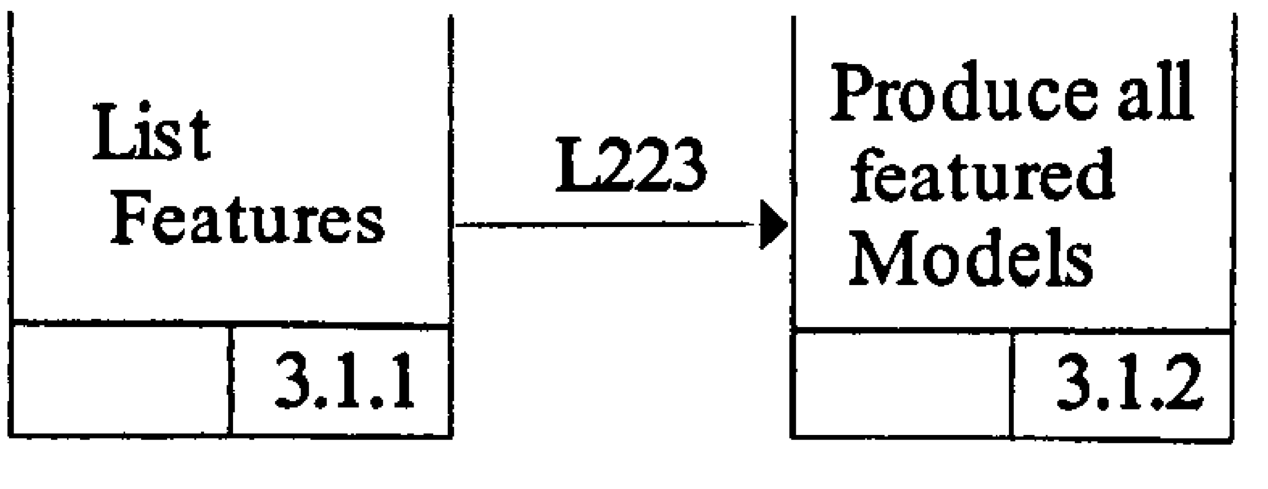


Figure 11 "Decomposition of Features and Options"

3.1.1 List Features

The CE will recover all the features available for the new model.

3.1.2 Produce all Feature Models

The CE also calls this activity 'feature walks'. The cost estimator will perform all the feature walks to establish the profitability & check ABS (Affordable Business Structure).

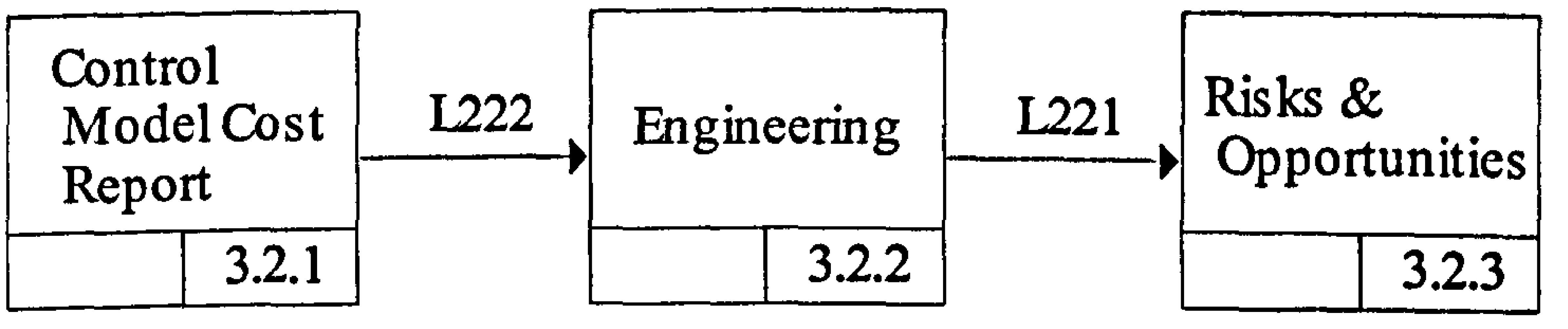


Figure 12 "Decomposition of Risks and Opportunities"

3.2.1 Control Model Cost Report

The Control Model Cost Report is probably the biggest contributions of the cost estimator to the car development process. For this output the cost estimator produces piece costs and tooling costs, in both of which he will further produce a target report and a status report. For the Piece Costs (Target) and the Tooling Costs (Target) he produces estimates-guides of how much the specific piece should cost in the company in order to make the desired profit. For the Piece Costs (Status) and Tooling Costs (status) he produces estimates of where currently the costs are standing.

3.2.2 Engineering

From the outputs, the engineering department uses the product definition, legal requirements, market requirements and current BOM to create the new BOM

3.2.3 Risks and Opportunities

What the Cost Estimator does in this case is to create different possible variance analysis reports, assuming from his experience, what are the possible difficulties that the product might encounter in the future.

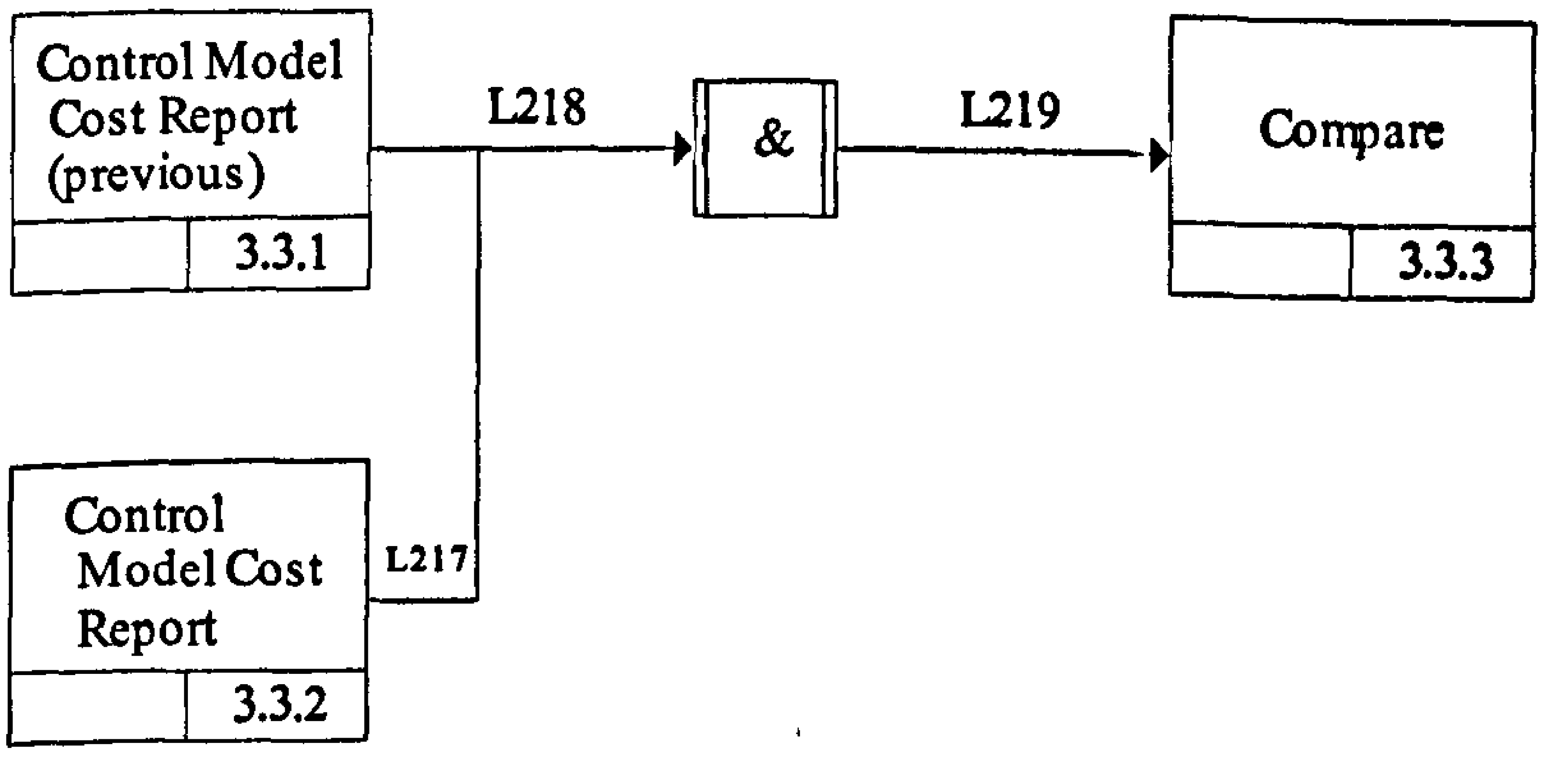


Figure 13 "Decomposition of Variance Analysis"

The purpose of this function was to give documentary evidence of what had changed from previous report to next. To be able to check if the product is aligning with the ABS and target costs.

3.4.0 Market Requirements

Market requirements are something that have to justify local requirements. E.g. in England a car must have right-steering wheel drive which is different than the rest of the European market. Other example would be that a mirror in US must have a warning sign embedded to it that is no existent in Europe. All these market requirements have implications in cost. It is also evident that the more different market requirements you have, the more the costs are increased.

3.4.1 Legal Requirements

With legal requirements we mean the restrictions placed by government laws. E.g. if there is a legal requirement of placing six airbags in all cars, there is a corresponding cost that cannot be avoided, and the cost estimator has to calculate this when his performing his feature walks.

3.4.2 Current Vehicle Data

The cost estimator tries to utilise as much as possible his historical data which has been collected throughout the years.

3.4.3 Engineering

From the inputs, the engineering department uses the product definition, legal requirements, market requirements and current BOM to create the new BOM.

3.4.4 BOM

The bill of Materials will include every single part and material required to create the component. This is a compulsory data that needs to be provided to the cost-estimating department in order to produce their cost estimates

3.4.5 Create Status Costs

This cost represents the actual cost that would cost the company if it was going on production at that specific time.

3.4.6 Create Target Costs

These are the desired costs that the ABS structure is dictating.

3.4.7 Create Target Proposal

3.4.8 Create Final Estimate

If this process is followed, it means that all the cost targets specified by the company were met. Otherwise you enter negotiations.

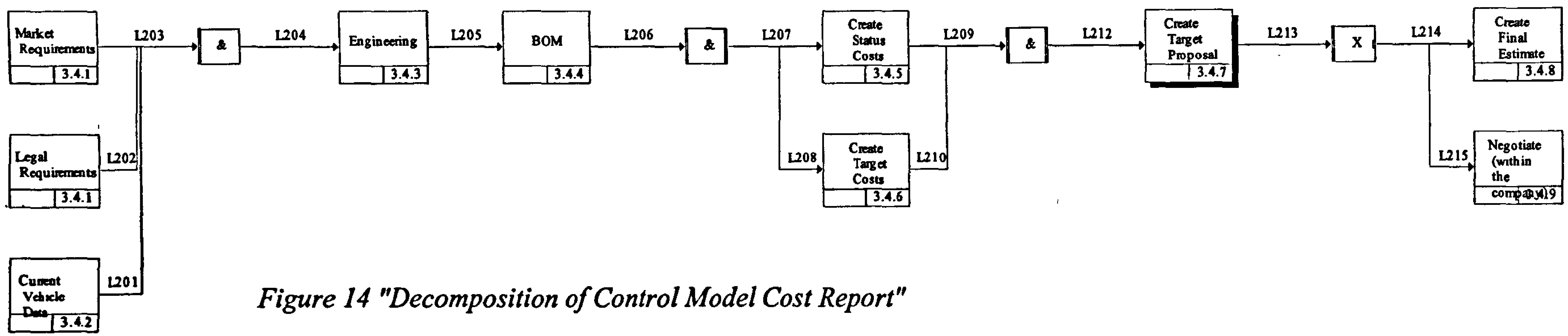


Figure 14 "Decomposition of Control Model Cost Report"

3.4.9 Negotiate (within the company)

In case the status estimate produced by the engineer does not meet the target, the estimator is involved in the following team trying to meet the targets. The people in these teams are the from the following departments:

- Engineering
- Sales & Marketing (to remove a feature)
- Purchasing (to try and find other sources and suppliers)
- Project Finance (to ensure if any changes made from these negotiations are worthing or not)
- Cost estimating

3.4.7.1 BOM

The bill of Materials will include every single part and material required to create the component. This is a compulsory data that needs to be provided to the cost-estimating department in order to produce its cost estimates.

3.4.7.2 Engineering

From the inputs, the engineering department uses the product definition, legal requirements, market requirements and current BOM to create the new BOM.

3.4.7.3 Suppliers Presentation

In case the supplier is involved in the full product development their input will provide BOM and other very useful information to the CE.

3.4.7.4 Benchmarking

Effectively, this is a comparative analysis, meaning to compare different quotes between suppliers for the same product; for example you could compare headlamps quotes to decide what should be the right price.

3.4.7.5 QAFs (Quotation analysis forms) Trading

This is a very similar function to benchmarking. The main difference is that the estimator is looking at fine commodities of the whole product. For example if the estimator has received two quotes from different suppliers, by comparing specific parts, like the dials of the speedometer or the PCB (printed circuit board) he will be able to see if one is charging more than the other. It has to be mentioned here that this process is based on commercial knowledge. At no point the estimator is using any scientific data to backup his estimates.

3.4.7.6 Purchase

The CE will consult the purchase department for additional information about the capabilities of the specific supplier. The information available from this source might be about the historic data available for this supplier. It has to be mentioned here that purchase is the main gateway between supplier and the company; therefore it has first-hand, uncorrupted information.

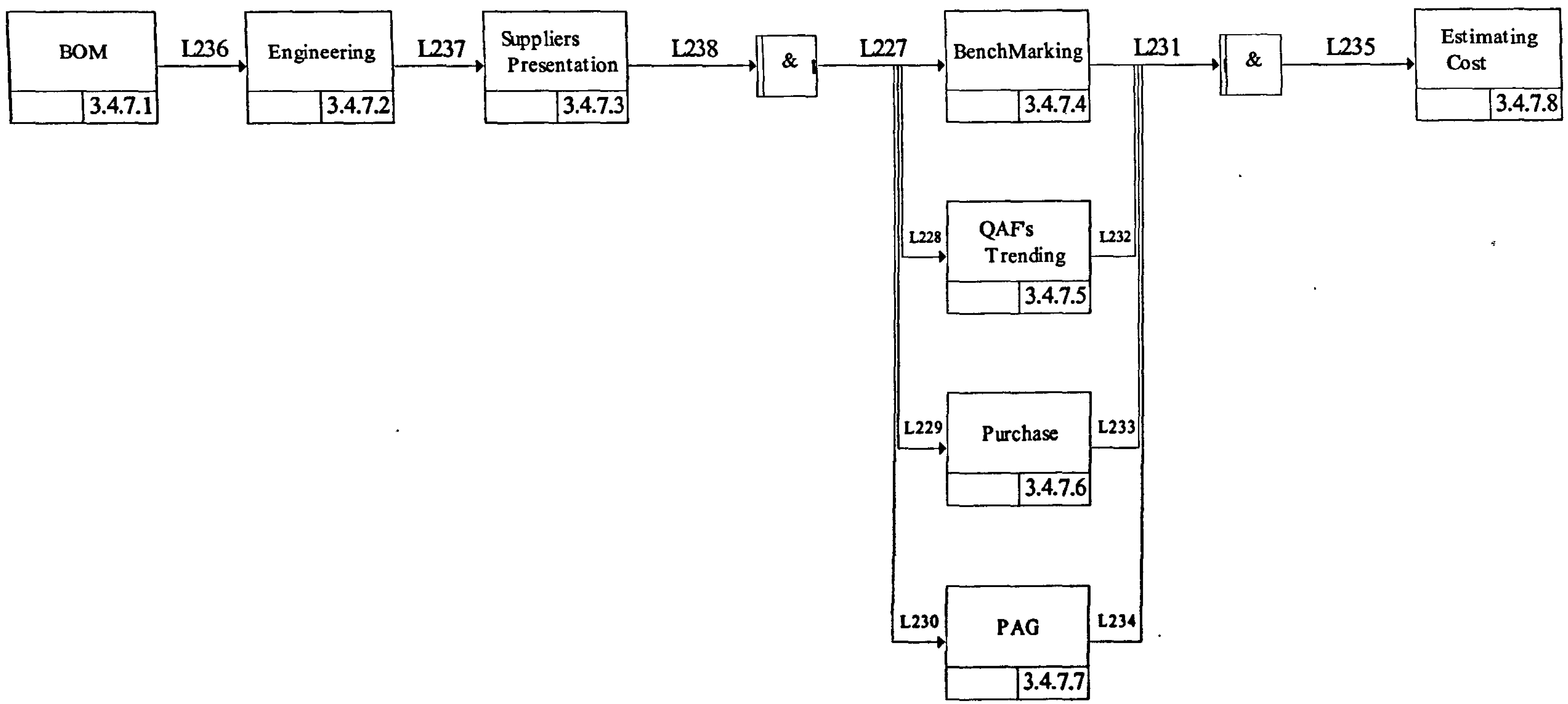


Figure15 "Decomposition of Control Model Cost Report"

APPENDIX D1

Guide to develop FAST

Define Functional Decomposition

The functions are categorised into three groups:

- Basic Functions
- Task Functions
- Supporting Functions

The figure below presents the guide used to analyse the functions of a product.

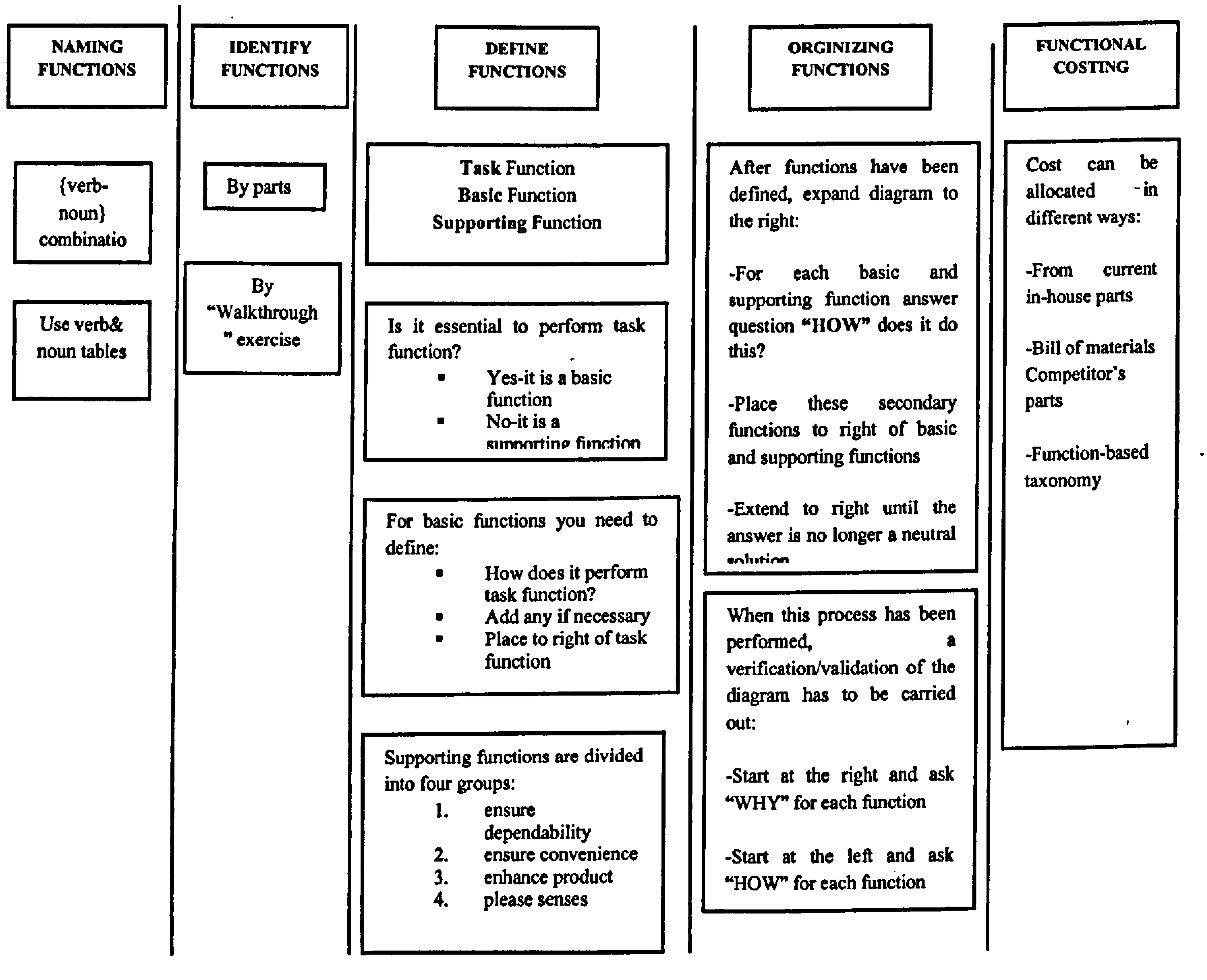


Figure: Guide to Functional Decomposition

The next sections will demonstrate how to perform the functional decomposition.

<u>Functional Analysis/Functional Decomposition</u>

First step concerns the functional decomposition. There are three fundamental steps in functional analysis:

1. Naming Functions
2. Identify Functions
3. Organizing Functions

Naming Function

- Functions will have to be described in a {verb-noun} combination
- Avoid the verbs "be" or "provide"
- Noun cannot be a part, activity or operation
- The users' viewpoint has to be maintained
-

Identify Functions

- Functions can be identified by parts:
  - What does "it" do from the customer's point of view?
  - "it" might be:
    - Elements
    - Features
    - Labour operation
    - Activity
    - Material element
    - Tolerance
    - Requirements
- Can be identified by "Walkthrough" exercise
  - As if you are using the product
  - Steps in process

List of verbs to describe those activities include:

Verbs

Absorb	Control	Hide	Minimize	Rotate
Actuate	Convert	Hold	Modulate	Satisfy
AidCreate	Ignite	Mount	Seal	Secure
Allow	Direct	Impart	Move	Shield
Amplify	Ease	Impede	Open	Shorten
Apply	Emit	Induce	Position	Space
Assist	Emphasize	Inject	Preserve	Standardize
Assure	Enclose	Instruct	Prevent	Steer
Avoid	Ensure	Insulate	Promulgate	Support
Change	Establish	Interrupt	Protect	Suspend
Close	Exude	Limit	Receive	Time
Collect	Facilitate	Locate	Rectify	Tolerate
Comfort	Fasten	Maintain	Reduce	Transfer
Conduct	Filter	Maximize	Repel	Transmit
Contain	Guard	Mesh	Resist	

Ullman (1997)

List of nouns:

Examples of nouns used:

Nouns

Access	Decoration	Flux	Noise	Task
Odor	Density	Force	Aesthetics	Time
Area	Dependability	Friction	Oxidization	Torque
Care	Deterioration	Heat	Pressure	Dust
Catalysis	Direction	Horsepower	Protection	User
Weight	Uniformity	Image	Radiation	Rust
Color	Emissivity	Information	Repair	Flow
Fluid	Energy	Injury	Variation	Voltage
Current	Vibration	Insulation	Stability	Status
Damage	Corrosion	Light	Volume	

Ullman (1997)

Organise Functions

The organisation of the function is done using the Functional Analysis System Technique (FAST) (see section 2.3.2). FAST is a road mapping of functions. It's an organised way of breaking down complicated systems into parts. An example of a light bulb can be seen in figure 6-12.

The natural route of the diagram is from left to right. The reasoning behind this is that you try to explain *how* you are going to satisfy a basic function of your system. Again by approaching the diagram from right to left you are explaining *why* you performed a specific function. The dotted lines separate the basic functions from the supporting ones of your system.

Defining Functions

Functions are categorised into the following:

- Task Function
- Basic Function
- Supporting Function
- Sub-Function

Task function is a function that fulfils the overall need and wants of the customer.

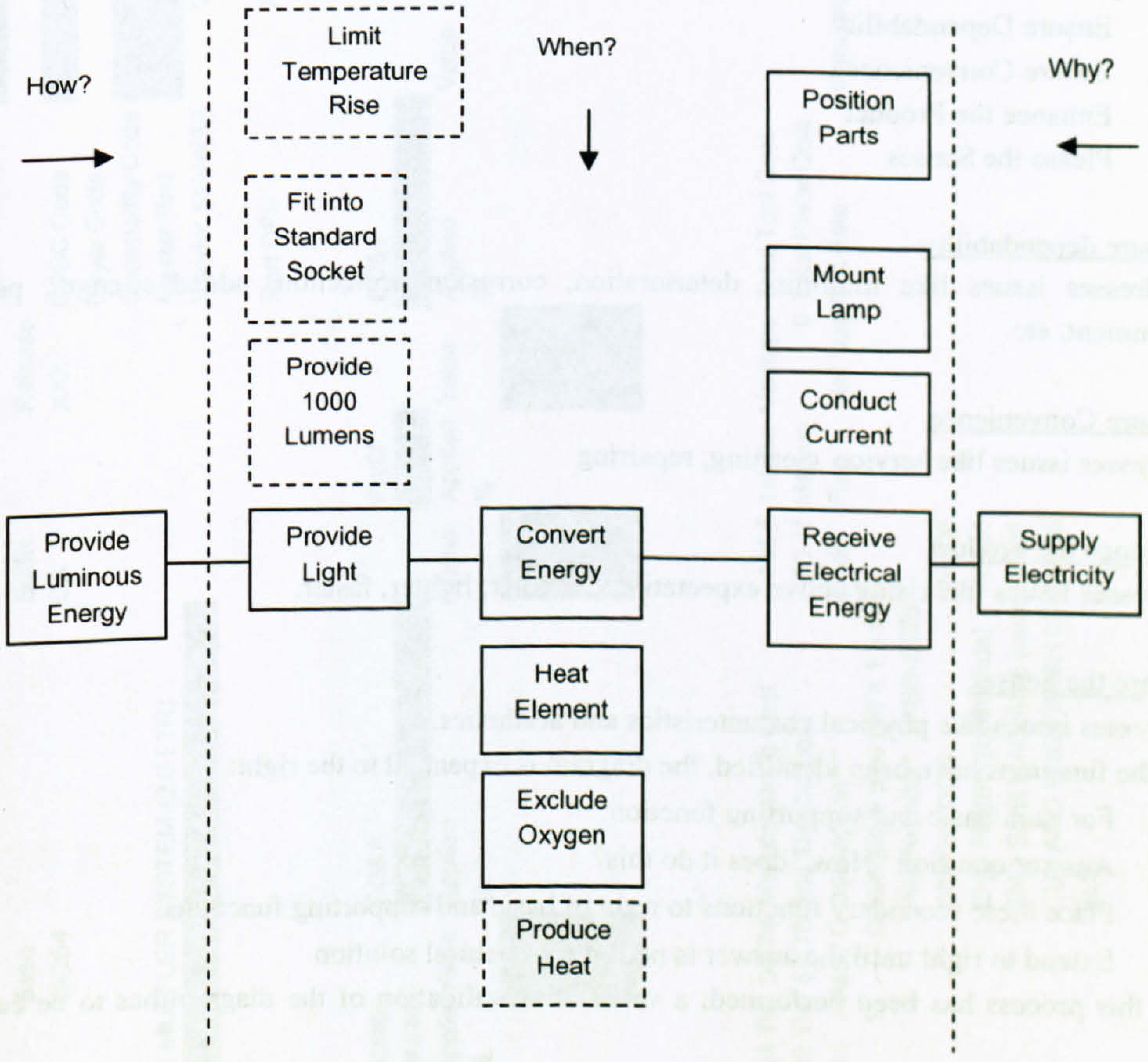


Figure 0-1: Example of a FAST Diagram-Bulb (SAVE, 2004)

Basic function is a required function that <u>must</u> be fulfilled in order to provide the task function.

Supporting function is a characteristic not essential to the user, but they want it because it improves performance and makes it dependable, makes it more convenient or more pleasing to the senses. It is essential to increase the product acceptance by satisfying the wants of the customer. It is the basis for buying decisions, user's performance appraisals and distinguishing product from competition.

Functions are divided into basic and supporting functions.

- Question: Is it essential to perform a task function?
    - Yes-it is a **basic function**
    - No-it is a **supporting function**

The two different functions are then organised. For the **basic functions** you need to define:

- How does it perform task function?
- Add any if necessary
- Place to right of task function

The **supporting functions** are divided into four groups:

1. Ensure Dependability
2. Ensure Convenience
3. Enhance the Product
4. Please the Senses

<u>1) Ensure dependability</u>
It addresses issues like minimise deterioration, corrosion protection, added strength, protect environment, etc.

<u>2) Ensure Convenience</u>
It addresses issues like service, cleaning, repairing

<u>3) Enhance the Product</u>
It addresses issues like rising above expectations, smaller, lighter, faster.

<u>4) Please the Senses</u>
It addresses issues like physical characteristics and aesthetics.
After the functions have been identified, the diagram is expanded to the right:

- For each basic and supporting function.
- Answer question "How" does it do this?
- Place these secondary functions to right of basic and supporting functions.
- Extend to right until the answer is no longer a neutral solution

When this process has been performed, a verification/validation of the diagram has to be carried out:

- Start at the right and ask the question "WHY?" for each function
- Start at the left and ask the question "HOW?" for each function
- No overpass

Appendix D2-Muffler Estimate

Estimator	[redacted]			Created Date	[redacted]		######
Estimator Code				Modified Date			######
	Base	Suffix	Release				
Lead Part No.	5K254	CA	XXX	CPSC Code	[redacted]		
Handed Part No.				Buyer Code			
Comparator Part No.				Commodity Code	[redacted]		
Part Description	MUFFLER SYSTEM (2.0 LTR)			Master Part			
Source Country Code	[redacted]			Vendor Share(%)	100		
Key ID				Part DPV	700		5
Comments							
Totals:							

	Scrap		SG&A		Profit		ED&T		Com| Total MU Value
Category									
Defaults	#####		[redacted]		[redacted]		[redacted]		####
	Applie %	Value	Applied %	Value	Applied %	Value	Applied %	Value	Applied %
2nd Tier		[redacted]		[redacted]		[redacted]			0 [redacted]
Material									0
Labor									0
Overhead									0
BOM Item Markups									
Combined Totals									
Totals:									

Source Currency	1st Tie 30.78	Manufacturing Cost	134.5	1st Tier Markups	Total Tool Cost 0
Economic Level	1st Tie 63.78	2nd Tier Content	30.11	Markup 0	Total Piece Cost

More?		No.	Assy Q	Description	Code	Flag	Mat Usa	Mat Rate	Man Level	LB G	Lab Mins	Lab Rate	Pieces /Ho	Mat Co	Item Co	Compo	Manuf Cost
+	2	1	0	Inlet Stub pipe (50 x 1.5 thi													
+	2			Part Number: 97BB-5K25													
+	2			INSPECTION	2E+06					AA	0	0.7694	600		0.006	DEM	0.006
+	2			END FINISH (both ends)	7E+06					AB	0	0.8039	300		0.044	DEM	0.044
+	2			END SIZE MACHINE (one	7E+06				1	AB	0.2	0.8039	300		0.198	DEM	0.198
+	2			CUT AND END FINISH M/	7E+06				1	AB	0.1	0.8039	600		0.106	DEM	0.106
	2			SUB							0.3			0	0.355	DEM	0.355
	1	2	0	Inlet Flange			1	1.5						1.5	1.5	DEM	1.5
+	2	3	0	Inlet Pipe													

+	2			Part Number: 97BB-5K25													
+	2			INSPECTION	2E+06					AA	0	0.7694	150		0.026	DEM	0.026
+	2			TACK WELD RIENFORCE	7E+06				1	AB	0.1	0.8039	600		0.102	DEM	0.102
+	2			END FINISHING MACHIM	7E+06					AB	0	0.8039	150		0.088	DEM	0.088
+	2			CUTTING MACHINE (snal	7E+06					AB	0	0.8039	150		0.156	DEM	0.156
+	2			AUTO TUBE BENDER (2 I	7E+06	D			1	AB	0.4	0.8039	150		0.322	DEM	0.322
+	2			CUT AND FINISH MACHII	7E+06				1	AB	0.1	0.8039	600		0.106	DEM	0.106
+	2			S/S TUBE 409 50 x 1.5 x 3			0.5	7.15						3.575	3.575	DEM	3.575
	2			SUB							0.6			3.575	4.514	DEM	4.514
+	2	4	0	Intermidiate Pipe													
+	2			Part Number: 97BB-5K25													
+	2			INSPECTION	2E+06					AA	0	0.7694	55		0.07	DEM	0.07
+	2			END FINISHING MACHINI	7E+06					AB	0	0.8039	55		0.242	DEM	0.242
+	2			END SIZE (Both Ends)	7E+06					AB	0	0.8039	55		0.242	DEM	0.242
+	2			CUTTING MACHINE	7E+06					AB	0	0.8039	55		0.428	DEM	0.428
+	2			AUTO TUBE BENDER (7 I	7E+06	D			1	AB	1.6	0.8039	38		1.286	DEM	1.286
+	2			CUT AND FINISHING MA(	7E+06				1	AB	0.1	0.8039	600		0.106	DEM	0.106
+	2			S/S TUBE 409 50 x 1.5 x 2			2.48	7.15						17.73	17.73	DEM	17.732
	2			SUB							1.7			17.73	21.05	DEM	21.046
+	2	5	0	REINFORCEMENT													
+	2			Part Number: 97BB-5K25													
+	2			INSPECTION	2E+06					AA	0	0.7694	600		0.006	DEM	0.006
+	2			END FINISHING MACHINI	7E+06				1	AB	0.1	0.8039	600		0.102	DEM	0.102
+	2			CUT AND FINISHING MA(	7E+06				1	AB	0.1	0.8039	600		0.106	DEM	0.106
+	2			S/S TUBE 409 53 X 1.0 X ·			0.047	5.44						0.256	0.256	DEM	0.256
	2			SUB							0.2			0.256	0.47	DEM	0.47
+	2	6	0	TAIL PIPE													
+	2			Part Number: 97BB-5K25													
+	2			INSPECTION	2E+06					AA	0	0.7694	182		0.021	DEM	0.021
+	2			END FINISH BOTH ENDS	7E+06					AB	0	0.8039	182		0.062	DEM	0.062
+	2			TUBE CUT ANGLED EXIT	7E+06					AB	0	0.8039	182		0.129	DEM	0.129
+	2			TUBE CUTTING MACHINI	7E+06					AB	0	0.8039	182		0.129	DEM	0.129
+	2			AUTO TUBE BENDER (1 I	7E+06	D			1	AB	0.33	0.8039	182		0.265	DEM	0.265
+	2			CUT AND END FINISH M/	7E+06				1	AB	0.1	0.8039	600		0.106	DEM	0.106
+	2			S/S TUBE 304 45 X 1.5 X :			0.215	8.1905						1.761	1.761	DEM	1.761
	2			SUB							0.43			1.761	2.666	DEM	2.666

+	2	7	0 SUB ASSY INLET FLANGI										
+	2		Part Number: 97BB-5K25										
+	2		HANDLING ROBOTER	2E+06			AB	0.65	0.268	92		0.281 DEM	0.281
+	2		MIG WELDING EQUIPMEI	1E+06			1 AB	0.65	0.8039	92		0.567 DEM	0.567
+	2		SIZE FLANGE / REINFOR	7E+06			1 AB	0.1	0.8039	600		0.102 DEM	0.102
	2		SUB					1.4			0	0.951 DEM	0.951
+	2	8	0 WELD INLET STUB AND I										
+	2		Part Number: 97BB-5K25										
+	2		WELDING HEAD FOR PIF	1E+06			AB	1.1	0.268	55		0.46 DEM	0.46
+	2		ROBOTER	2E+06			AB	1.1	0.268	55		0.552 DEM	0.552
+	2		TURN TABLE	8E+05			1 AB	1.1	0.8039	55		1.038 DEM	1.038
	2		SUB					3.3			0	2.05 DEM	2.05
+	2	9	0 END PLATE - FRONT BO:										
+	2		Part Number: 97BB-5K25										
+	2		INSPECTION	2E+06			AA	0	0.7694	600		0.006 DEM	0.006
+	2		PROGRESSION TOOL PF	6E+06			1 AB	0.1	0.8039	600		0.105 DEM	0.105
+	2		WIND OFF REEL	7E+06			AA	0	0.7694	600		0.028 DEM	0.028
+	2		Front Box End Plates 2 off		0.674	3.359					2.264	2.264 DEM	2.264
	2		SUB					0.1			2.264	2.403 DEM	2.403
+	2	10	0 FRONT BOX BAFFLE PLA										
+	2		Part Number: 97BB-5K25										
+	2		INSPECTION	2E+06			AA	0	0.7694	600		0.006 DEM	0.006
+	2		PROGRESSION TOOL PF	6E+06			1 AB	0.1	0.8039	600		0.105 DEM	0.105
+	2		WIND OFF REEL	7E+06			AA	0	0.7694	600		0.028 DEM	0.028
+	2		FRONT BOX BAFFLE PLA		0.527	3.359					1.77	1.77 DEM	1.77
	2		SUB					0.1			1.77	1.909 DEM	1.909
+	2	11	0 PERF TUBE (BOUGHT OI										
+	2		Part Number: 97BB-5K25										
+	2		INSPECTION	2E+06			AA	0	0.7694	200		0.019 DEM	0.019
+	2		REDUCE END DIA (BOTH	7E+06			1 AB	0.2	0.8039	300		0.198 DEM	0.198
+	2		MIG/MAG WELDER FOR I	1E+06			AB	0.3	0.268	200		0.126 DEM	0.126
+	2		ROBOT HEAD FOR WELI	1E+06			AB	0	0.8039	200		0.021 DEM	0.021
+	2		AUTO TUBE PRESS	7E+06 D			0.5 AB	0.15	0.8039	200		0.121 DEM	0.121
+	2		INSPECTION	2E+06			1 AA	0.1	0.7694	600		0.083 DEM	0.083
+	2		PROGRESSION PRESS A	6E+06			1 AB	0.15	0.8039	400		0.153 DEM	0.153
+	2		WIND OFF REEL	7E+06			AA	0	0.7694	600		0.028 DEM	0.028

+	2			PERF BLANKS 409 S/S		0.599	3.2994						1.976	1.976	DEM	1.976
	2			SUB						0.9			1.976	2.915	DEM	2.915
+	2	12	0	PERF TUBE (BOUGHT OI												
+	2			Part Number: 97BB-5K25												
+	2			INSPECTION	2E+06				AA	0	0.7694	200		0.019	DEM	0.019
+	2			REDUCE END DIA (BOTH	7E+06			1	AB	0.2	0.8039	300		0.198	DEM	0.198
+	2			MIG/MAG WELDER FOR I	1E+06				AB	0.3	0.268	200		0.126	DEM	0.126
+	2			ROBOT HEAD FOR WELI	1E+06				AB	0	0.8039	200		0.021	DEM	0.021
+	2			AUTO TUBE PRESS	7E+06			0.5	AB	0.15	0.8039	200		0.298	DEM	0.298
+	2			INSPECTION	2E+06			1	AA	0.1	0.7694	600		0.083	DEM	0.083
+	2			PROGRESSION PRESS A	6E+06			1	AB	0.15	0.8039	400		0.153	DEM	0.153
+	2			WIND OFF REEL	7E+06				AA	0	0.7694	600		0.028	DEM	0.028
+	2			PERF BLANK 409 S/S as		0.545	3.2994						1.798	1.798	DEM	1.798
	2			SUB						0.9			1.798	2.724	DEM	2.724
	1	13	0	E GLASS SOUND MATER		1	2.482						2.482	2.482	DEM	2.482
+	2	14	0	SUB ASSEMBLE FRONT I												
+	2			Part Number: 97BB-5K25												
+	2			INSPECTION	2E+06				AA	0	0.7694	67		0.057	DEM	0.057
+	2			TURN TABLE	8E+05				AB	0	0.8039	67		0.125	DEM	0.125
+	2			MIG WELD 4 X 20 IN 2 PL	1E+06			1	AB	0.9	0.8039	67		0.785	DEM	0.785
+	2			ASSY BAFFLES TO TUBE	8E+05				AB	0	0.8039	67		0.036	DEM	0.036
	2			SUB						0.9			0	1.005	DEM	1.005
+	2	15	0	FRONT BOX												
+	2			Part Number: 97BB-5K25												
+	2			SPOT WELDER SPECIAL	1E+06				AB	0	0.8039	600		0.04	DEM	0.04
+	2			GUILLOTINE	7E+06			1	AB	0.1	0.8039	600		0.092	DEM	0.092
+	2			WIND OFF REEL	7E+06				AA	0	0.7694	600		0.028	DEM	0.028
+	2			OUTER CASE ALUMINISE		1.524							-0.093	-0.093	DEM	
+	2			Inner Case 409 S/S 506 x		0.985	3.7094						3.654	3.654	DEM	3.654
	2			SUB						0.1			3.561	3.721	DEM	3.721
+	2	16	0	MUFFLER ASSEMBLY CE												
+	2			Part Number: 97BB-5K25												
+	2			INSPECTION	2E+06				AA	0	0.7694	120		0.032	DEM	0.032
+	2			FLATTEN BOX SIDES	1E+06				AB	0	0.8039	113		0.399	DEM	0.399
+	2			END SIZE BOTH ENDS O	7E+06				AB	0	0.8039	120		0.11	DEM	0.11

+	2		LOCKSEAM MUFFLER EI	1E+06			AB	0	0.8039	120		0.376 DEM	0.376
+	2		PRESS FIT MUFFLER EN	1E+06			AB	0	0.8039	120		0.25 DEM	0.25
+	2		HYDRAULIC RAM ASSEN	1E+06			AB	0	0.8039	120		0.25 DEM	0.25
+	2		FLANGE ENDS OF CASE	1E+06			AB	0	0.8039	120		0.25 DEM	0.25
+	2		FORM&LOCKSEAM MUFI	1E+06			2 AB	1	0.8039	120		1.054 DEM	1.054
	2		SUB					1			0	2.72 DEM	2.72
+	2	17	0 REAR BOX FRONT END I										
+	2		Part Number: 97BB-5K25										
+	2		INSPECTION	2E+06			AA	0	0.7694	600		0.006 DEM	0.006
+	2		HIGH PERF TRANS PRES	6E+06			1 AB	0.1	0.8039	600		0.485 DEM	0.485
+	2		DBL COIL REEL	7E+06			AA	0	0.7694	600		0.02 DEM	0.02
+	2		REAR BOX END PLATE (I		1.73	4.257					7.365	7.365 DEM	7.365
	2		SUB					0.1			7.365	7.876 DEM	7.876
+	2	18	0 REAR BOX REAR END PI										
+	2		Part Number: 97BB-5K25										
+	2		INSPECTION	2E+06			AA	0	0.7694	600		0.006 DEM	0.006
+	2		HIGH PERF TRANS PRES	6E+06			1 AB	0.1	0.8039	600		0.356 DEM	0.356
+	2		DBL COIL REEL	7E+06			AA	0	0.7694	600		0.02 DEM	0.02
+	2		REAR BOX REAR END PI		1.02	4.257					4.342	4.342 DEM	4.342
	2		SUB					0.1			4.342	4.724 DEM	4.724
+	2	19	0 FRONT BAFFLE										
+	2		Part Number: 97BB-5K25										
+	2		INSPECTION	2E+06			AA	0	0.7694	600		0.006 DEM	0.006
+	2		HIGH PERF TRANS PRES	6E+06			1 AB	0.1	0.8039	600		0.299 DEM	0.299
+	2		DBL COIL REEL	7E+06			AA	0	0.7694	600		0.02 DEM	0.02
+	2		STAINLESS SHEET 409 3		0.624	3.3594					2.096	2.096 DEM	2.096
	2		SUB					0.1			2.096	2.422 DEM	2.422
+	2	20	0 REAR BAFFLE										
+	2		Part Number: 97BB-5K25										
+	2		INSPECTION	2E+06			AA	0	0.7694	600		0.006 DEM	0.006
+	2		HIGH PERF TRANS PRES	6E+06			1 AB	0.1	0.8039	600		0.299 DEM	0.299
+	2		DBL COIL REEL	7E+06			AA	0	0.7694	600		0.02 DEM	0.02
+	2		STAINLESS SHEET 409 3		0.624	3.3594					2.096	2.096 DEM	2.096
	2		SUB					0.1			2.096	2.422 DEM	2.422
+	2	21	0 PLAIN TUBE OUTLET (ITI										

+	2			Part Number: 97BB-5K25												
+	2			INSPECTION	2E+06				AA	0	0.7694	200		0.019	DEM	0.019
+	2			END FORMING / SIZING (	7E+06			1	AB	0.3	0.8039	200		0.307	DEM	0.307
+	2			END FINISHING MACHINI	7E+06				AB	0	0.8039	200		0.057	DEM	0.057
+	2			CUT AND FINISH MACHII	7E+06			1	AB	0.1	0.8039	600		0.106	DEM	0.106
+	2			S/S TUBE 409 45 x 255 x		0.255	5.5						1.403	1.403	DEM	1.403
	2			SUB						0.4			1.403	1.891	DEM	1.891
+	2	22	0	INTER PERF TUBE - ITEI												
+	2			Part Number: 97BB-5K25												
+	2			INSPECTION	2E+06				AA	0	0.7694	200		0.019	DEM	0.019
+	2			REDUCE END DIA (BOTH	7E+06			1	AB	0.3	0.8039	200		0.298	DEM	0.298
+	2			MIG/MAG WELDER FOR I	1E+06				AB	0.3	0.268	200		0.126	DEM	0.126
+	2			ROBOT HEAD FOR WELI	1E+06				AB	0	0.8039	200		0.021	DEM	0.021
+	2			AUTO TUBE PRESS	7E+06			0.5	AB	0.15	0.8039	200		0.298	DEM	0.298
+	2			INSPECTION	2E+06				AA	0	0.7694	400		0.01	DEM	0.01
+	2			PROGRESSION PRESS A	6E+06			1	AB	0.15	0.8039	400		0.153	DEM	0.153
+	2			WIND OFF REEL	7E+06				AA	0	0.7694	600		0.028	DEM	0.028
+	2			STAINLESS SHEET 409 1		0.114	4.8294						0.551	0.551	DEM	0.551
	2			SUB						0.9			0.551	1.502	DEM	1.502
+	2	23	0	INLET PERF TUBE - ITEM												
+	2			Part Number: 97BB-5K25												
+	2			INSPECTION	2E+06				AA	0	0.7694	200		0.019	DEM	0.019
+	2			END FINISH (BOTH ENDS	7E+06			1	AB	0.3	0.8039	200		0.307	DEM	0.307
+	2			MIG/MAG WELDER FOR I	1E+06				AB	0.3	0.268	200		0.126	DEM	0.126
+	2			ROBOT HEAD FOR WELI	1E+06				AB	0	0.8039	200		0.021	DEM	0.021
+	2			AUTO TUBE PRESS	7E+06			0.5	AB	0.15	0.8039	200		0.298	DEM	0.298
+	2			INSPECTION	2E+06				AA	0	0.7694	600		0.006	DEM	0.006
+	2			PROGRESSION PRESS A	6E+06			1	AB	0.15	0.8039	400		0.153	DEM	0.153
+	2			DBL COIL REEL	7E+06				AA	0	0.7694	600		0.028	DEM	0.028
+	2			STAINLESS SHEET 409 1		0.332	3.3594						1.115	1.115	DEM	1.115
	2			SUB						0.9			1.115	2.073	DEM	2.073
+	2	24	0	U BEND												
+	2			Part Number: 97BB-5K25												
+	2			INSPECTION	2E+06				AA	0	0.7694	600		0.006	DEM	0.006
+	2			FIT STAINLESS STEEL W	8E+05				AB	0	0.8039	200		0.012	DEM	0.012
+	2			SPOT WELD HALF PRES:	1E+06				AB	0.25	0.268	240		0.096	DEM	0.096
+	2			PROGRESSION PRESS T	6E+06			1	AB	0.1	0.8039	600		0.103	DEM	0.103

+	2		DBL COIL REEL	7E+06			AA	0	0.7694	600		0.028 DEM	0.028
+	2		STAINLESS SHEET 409 2		0.495	4.8294					2.391	2.391 DEM	2.391
	2		SUB					0.35			2.391	2.636 DEM	2.636
+	2	25	0 TUNING TUBE										
+	2		Part Number: 97BB-5K25										
+	2		INSPECTION	2E+06			AA	0	0.7694	600		0.006 DEM	0.006
+	2		TUBE CUT OFF TO LENG	7E+06			AB	0	0.8039	600		0.039 DEM	0.039
+	2		TUBE BENDER	7E+06			1 AB	0.25	0.8039	240		0.335 DEM	0.335
+	2		TUBE CUT OFF	7E+06			1 AB	0.1	0.8039	600		0.119 DEM	0.119
+	2		409SS EXHAUST TUBING		0.16	6.005					0.961	0.961 DEM	0.961
	2		SUB					0.35			0.961	1.461 DEM	1.461
+	2	26	0 REAR BOX SUB ASSEMB										
+	2		Part Number: 97BB-5K25										
+	2		INSPECTION	2E+06			AA	0	0.7694	43		0.089 DEM	0.089
+	2		MIG WELDING FOR TUNI	1E+06			1 AB	0.25	0.8039	240		0.218 DEM	0.218
+	2		INDEXING TABLE	8E+05			AB	0	0.8039	43		0.195 DEM	0.195
+	2		ROBOT HEAD FOR WELD	1E+06			AB	0	0.8039	50		0.082 DEM	0.082
+	2		MIG/MAG WELDER FOR I	1E+06			AB	1.4	0.268	43		0.586 DEM	0.586
+	2		ASSEMBLE BAFFLES TO	8E+05			1 AB	1.4	0.8039	43		1.182 DEM	1.182
	2		SUB					3.05			0	2.353 DEM	2.353
+	2	27	0 REAR BOX										
+	2		Part Number: 97BB-5K25										
+	2		SPOT WELDER SPECIAL	1E+06			AB	0	0.8039	600		0.04 DEM	0.04
+	2		GUILLOTINE	7E+06			1 AB	0.1	0.8039	600		0.092 DEM	0.092
+	2		DBL COIL REEL	7E+06			AA	0	0.7694	600		0.028 DEM	0.028
+	2		INNER CASE 893 X 256 X		0.897	4.167					3.738	3.738 DEM	3.738
+	2		AL MILD STEEL OUTER C		1.378						-0.194	-0.194 DEM	
	2		SUB					0.1			3.544	3.703 DEM	3.703
+	2	28	0 REAR MUFFLER ASSEMB										
+	2		Part Number: 97BB-5K25										
+	2		INSPECTION	2E+06			AA	0	0.7694	100		0.038 DEM	0.038
+	2		SIZE INLET AND OUTLET	7E+06			AB	0	0.8039	100		0.132 DEM	0.132
+	2		LOCK SEAM MUFFLER E	1E+06			1 AB	0.6	0.8039	100		0.934 DEM	0.934
+	2		PRESS FIT MUFFLER EN	1E+06			AB	0	0.8039	100		0.3 DEM	0.3
+	2		HYDRAULIC RAM ASSEN	1E+06 D			AB	0	0.8039	100		0 DEM	0
+	2		FLANGE ENDS OF CASE	1E+06			AB	0	0.8039	100		0.3 DEM	0.3

+	2			FORM&LOCKSEAM MUFI	1E+06 D			3 AB	1.8	0.8039	100		1.447 DEM	1.447
	2			SUB					2.4			0	3.977 DEM	3.977
+	2	29	0	SUB ASSEMBLY REAR EI										
+	2			Part Number: 97BB-5K25										
+	2			INSPECTION	2E+06			AA	0	0.7694	43		0.089 DEM	0.089
+	2			WELD REAR BOX HANGE	1E+06 D			AB	0	0.8039	43		0 DEM	0
+	2			HANDLING ROBOTER	2E+06 D			AB	1.4	0.268	43		0.375 DEM	0.375
+	2			WELD TAIL PIPE TO REA	1E+06 D			1 AB	1.4	0.8039	43		1.125 DEM	1.125
	2			SUB					2.8			0	2.173 DEM	2.173
+	2	30	0	FINAL ASSEMBLY SYSTE										
+	2			Part Number: 97BB-5K25										
+	2			INSPECTION	2E+06			AA	0	0.7694	25		0.153 DEM	0.153
+	2			PRESSURE TESTING EQ	2E+06 D			1 AC	2.4	0.8392	25		2.014 DEM	2.014
+	2			WELDING HEAD (ROBOT	1E+06 D			AB	2.4	0.268	25		0.643 DEM	0.643
+	2			INDEX TURNTABLE ROB	8E+05 D			AB	0	0.8039	25		0 DEM	0
+	2			HANDLING ROBOTER	2E+06 D			AB	2.4	0.268	25		0.643 DEM	0.643
	2			SUB					7.2			0	5.348 DEM	5.348
	1	31	0	LABEL		1	0.1					0.1	0.1 DEM	0.1
	1	32	0	WELDING WIRE SURCHA		1	0.8					0.8	0.8 DEM	0.8
	1	33	0	HANGER - INLET PIPE		1	0.875					0.875	0.875 DEM	0.875
	1	34	0	HANGER - INTER PIPE X		1	1.75					1.75	1.75 DEM	1.75
	1	35	0	HANGER - REAR BOX		1	1.4					1.4	1.4 DEM	1.4
	1	36	0	E GLASS REAR BOX		1	2.733					2.733	2.733 DEM	2.733
	1	37	0	STEEL WOOL REAR BOX		1	1					1	1 DEM	1
	1	38	0	FLEX JOINT		1	27.87					27.87	27.87 DEM	27.87

Appendix D3

Relationship Tables

Table of Engine Size and Muffler Volume followed by graphical representations

Petrol

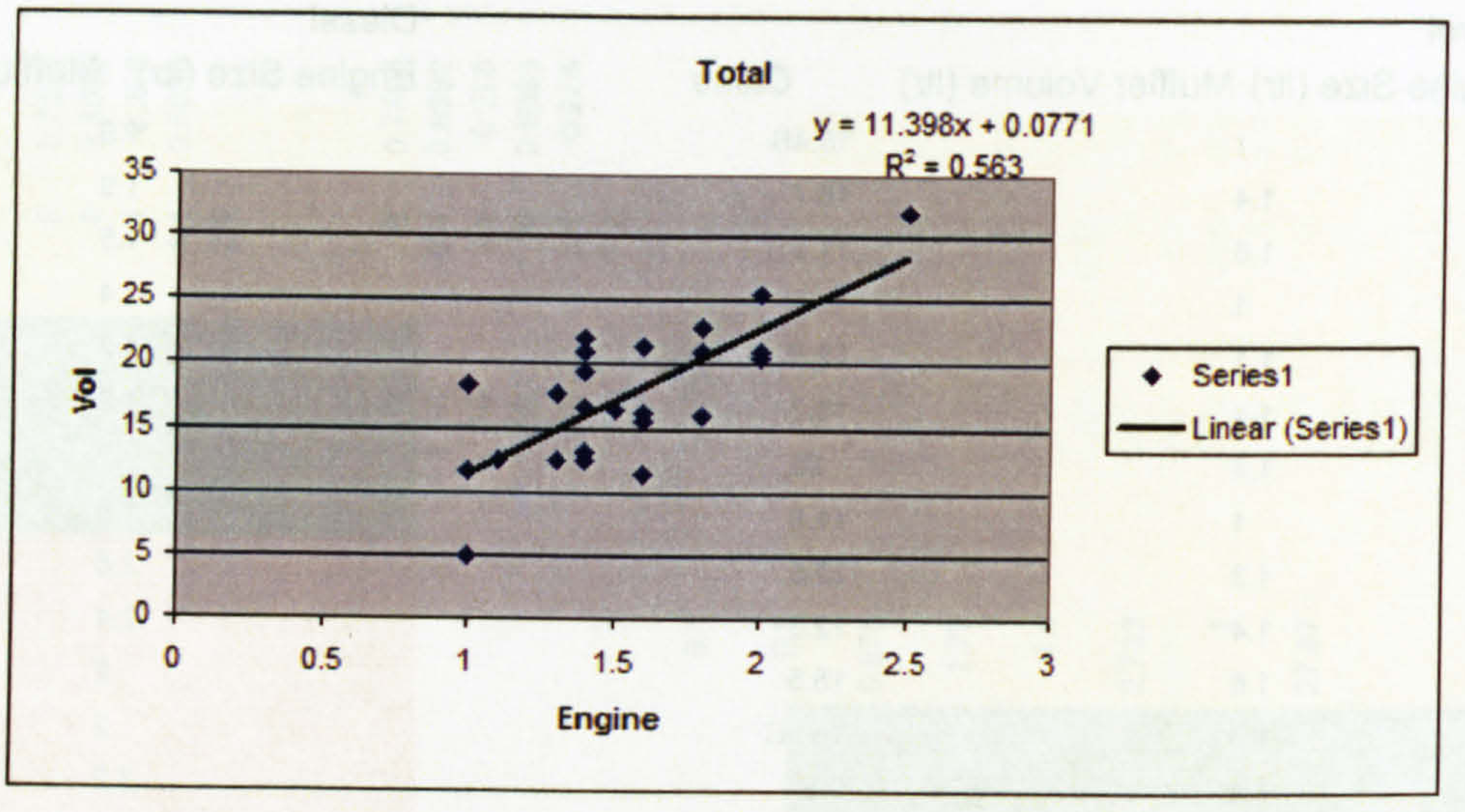
Engine Size (ltr)	Muffler Volume (ltr)	Class
1	18.4	B
1.4	16.7	
1.6	11.5	
1.	5	
1.1	12.5	
1.4	13.2	
1.4	22	
1	11.6	
1.3	12.5	
1.4	12.5	
1.6	15.5	
1.5	16.5	C
1.4	20.85	
1.3	17.8	
1.4	19.4	
1.6	16.2	
1.6	21.3	
1.8	22.8	C/D
2	25.4	
2	20.5	
1.8	16	
1.8	20.9	
1.8	21	
2	21	
2.5	32	

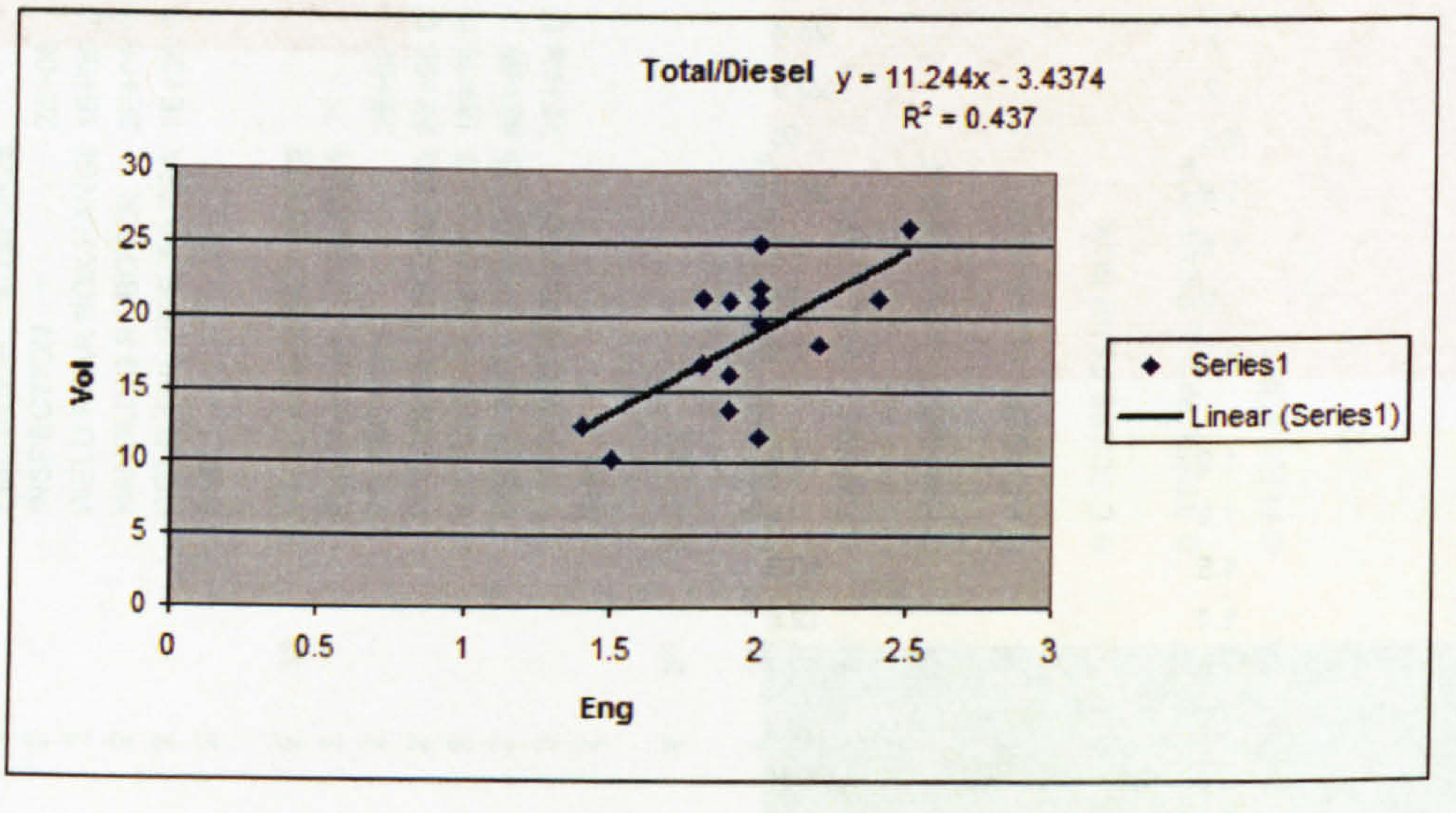
1.9	13.6
1.9	16
1.5	10.3
1.4	12.5
1.9	21
1.8	16.7
2	11.75
1.8	21.3
2.5	26.1

Diesel

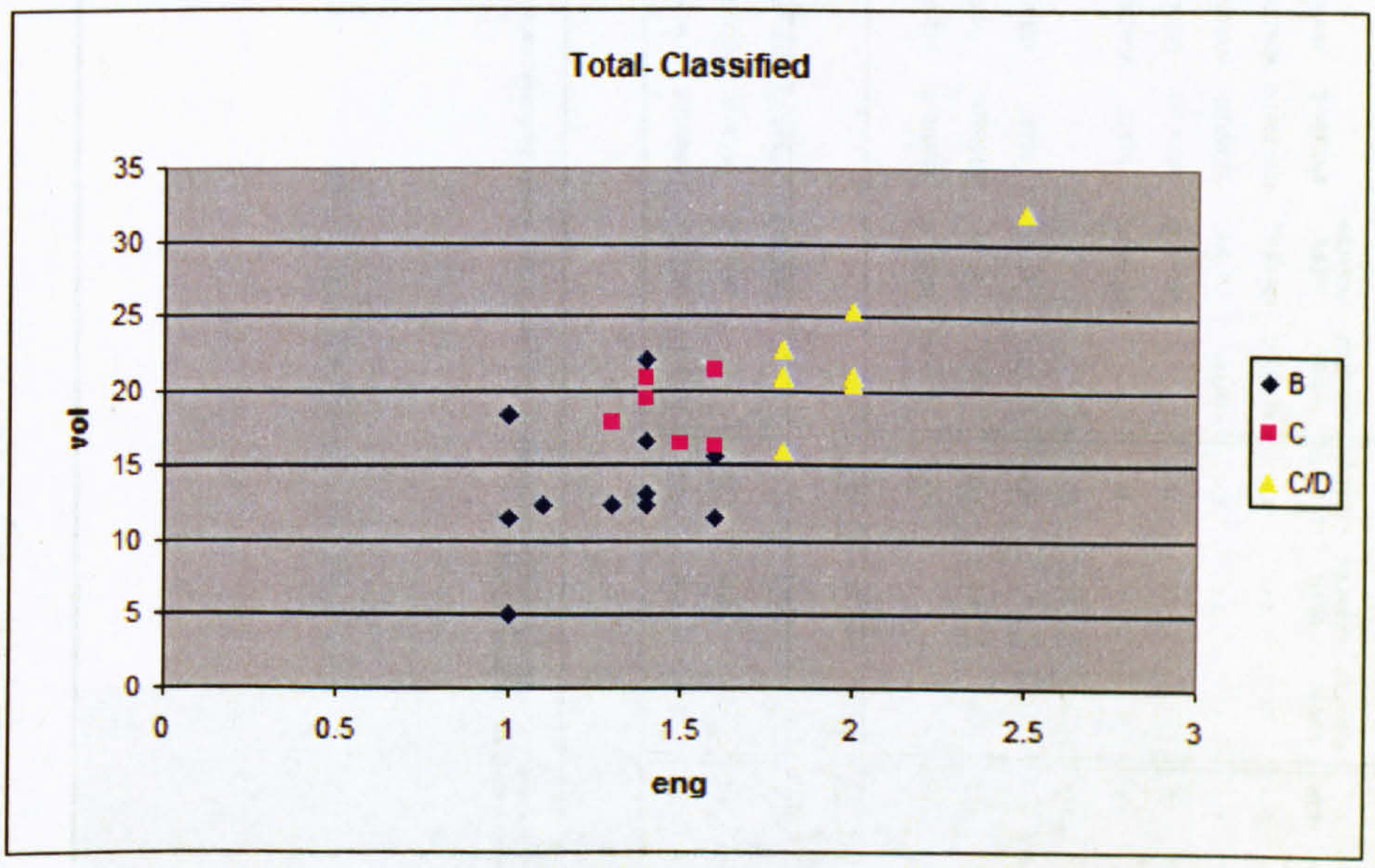
Engine Size (ltr)	Muffler Volume (ltr)	Class
1.9	13.6	B
1.9	16	
1.5	10.3	
1.4	12.5	
1.9	21	C
1.8	16.7	
2	11.75	
1.8	21.3	
2.5	26.1	C/D
2.4	21.2	
2	22	
2	25	
2.2	18	
2	19.5	
2	21	
2	21	
2	19.5	
2	21	
2	21	

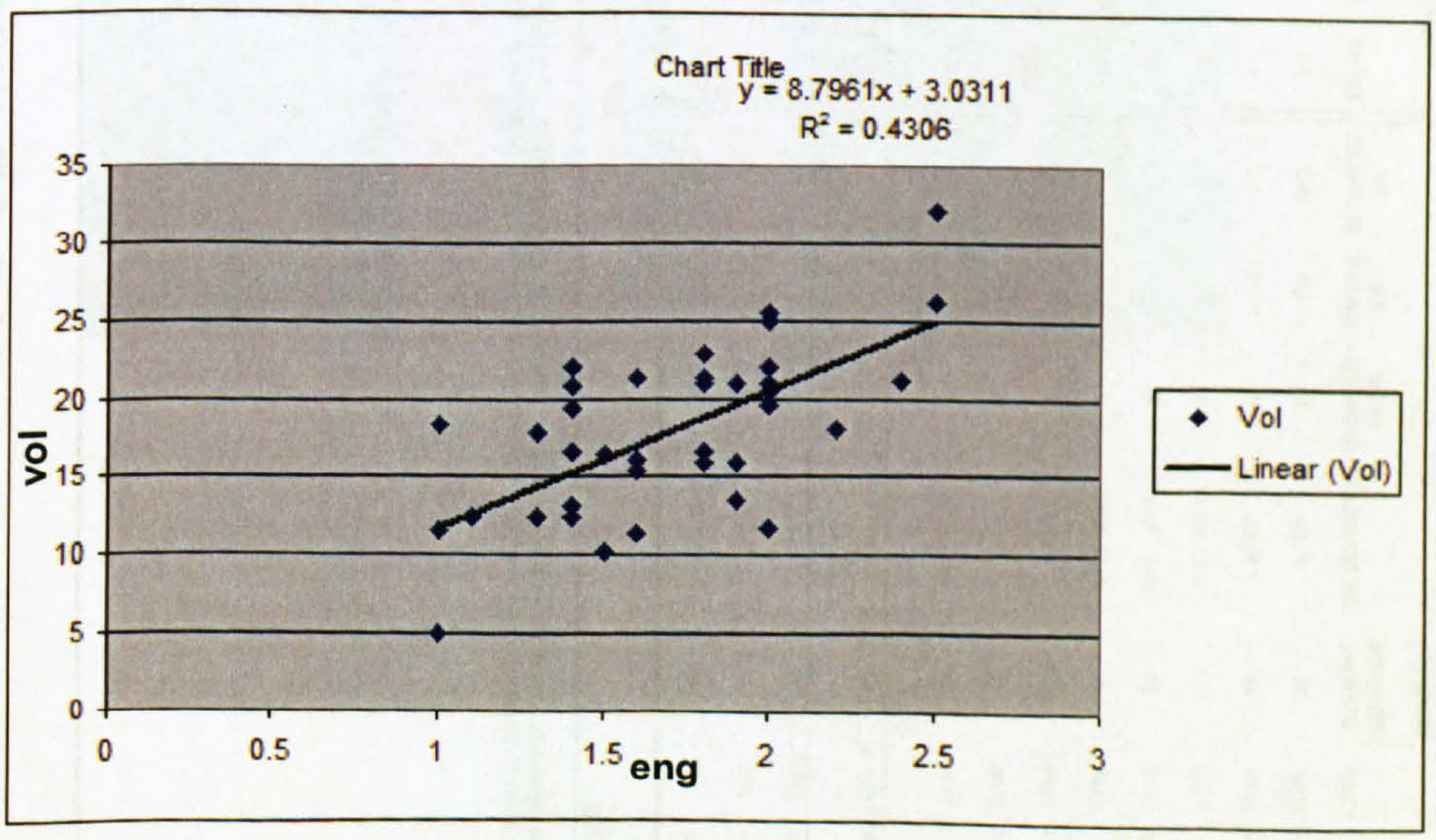
2.4	21.2
2	22
2	25
2.2	18





Different Classes of Cars





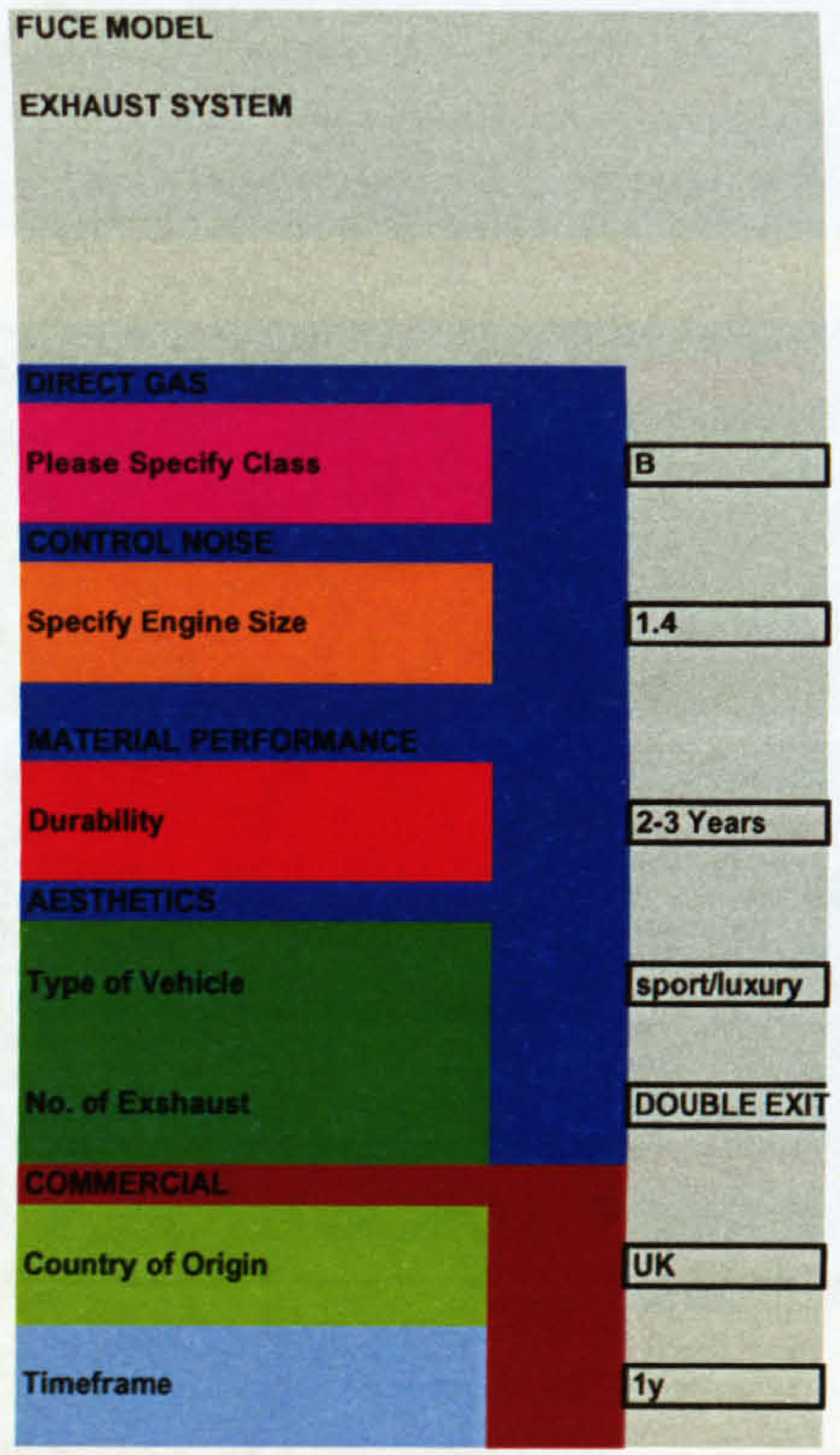
		GENERAL					MUFFLER VOLUME (L)				WEIGHT (KG)			EXTERNAL MATERIALS				COMMENTS
VEHICLE	YEAR	INTERPIPE O/D (mm)	DE COUPLER	No. of HANGERS	T/P VISIBLE	T/P STIFFENER	FRONT	REAR	TOTAL	xESW	MUFFLER FRONT	MUFFLER REAR	SYSTEM TOTAL	MUFFLER FRONT	MUFFLER REAR	INTERPIPE	TAILPIPE	
GM CORSA 1.0 12v	2000	38	FLEX	5	YES	NO	7.1	11.9	18.4	16.4	4.5	5.4	9.9	FERRITIC	FERRITIC	AUSTENITIC	AUSTENITIC	Straight-through absorption front & bleed-through 3-pass rear with absorption + internal resonator
GM CORSA 1.4 16v	2000	45	FLEX	5	YES	NO	5.4	11.3	16.7	11.9	4.4	5.1	9.5	ALUM	ALUM	FERRITIC	AUSTENITIC	Straight-through absorption front & bleed-through 3-pass rear with absorption + internal resonator
MERCEDES A 160	1998	41.5	BALLJOINT	3	NO	NO	N/A	11.5	11.5	7.2			16		FERRITIC	FERRITIC	FERRITIC	Single lockseam 2-pass with expansion
NISSAN MICRA 1.0	1999	38	BALLJOINT	5	YES	NO	N/A	6	5	5.9			16		FERRITIC	STEEL	AUSTENITIC	Single 'bleed-through' type 3-pass muffler
PEUGEOT 206 1.1	1998	42	BALLJOINT	3	YES	NO	N/A	12.5	12.5	11.4			?				-	3-pass bleed-through + internal resonator with edge-lock construction
RENAULT CLIO 1.4	1998	47.5	FLEX	2	NO	NO	2.2	11	13.2	9.4			15.6	ALUM	ALUM	STEEL	FERRITIC	Absorption front muffler & mechanical 3-pass bleed-through rear muffler with internal resonator in outlet
SKODA FABIA 1.4	2000	45	FLEX	5	NO	NO	4	18	22	15.7	3.4	8.1	11.5	ALUM	ALUM	FERRITIC	ALUM	Straight-through absorption front & bleed-through 3 pass rear with absorption with edge-lock construction
TOYOTA YARIS 1.0	1999	38	BALLJOINT	4	YES	NO	2.6	9	11.6	11.6			10.65	FERRITIC	FERRITIC	FERRITIC	FERRITIC	Tubular absorption front muffler & 3-pass bleed-through rear muffler with external resonator in inlet & outlet
	Mean Value =	42	Mean Value =	4			Mean Values =		13.9	11.3	Mean Value =		12.7					
B2XX 1.3 ReCam	2002	42	FLEX	3	NO	NO	-	12.5	12.5	9.6	N/A	5.96	10.65		FERRITIC	FERRITIC	AUSTENITIC	Single 3-pass muffler with external resonator in inlet & outlet pipes + Helmholtz chamber
B2XX 1.4 Sigma	2002	42	FLEX	3	NO	NO	-	12.5	12.5	8.9	N/A	5.46	10.35		FERRITIC	FERRITIC	AUSTENITIC	Single 3-pass absorption muffler with restrictor in inlet
B2XX 1.6 Sigma	2002	48	FLEX	4	NO	NO	3	12.5	15.5	9.7	2.00	5.85	12.35	FERRITIC	FERRITIC	FERRITIC	AUSTENITIC	Straight-through front resonator & 3-pass absorption rear muffler

OBSERVATIONS

B2XX stacks up well against it's competitors when reviewed against the primary technical comparators. For muffler volume versus engine swept volume, although not the lowest, on average this measure falls below the group mean value. For the two smaller engined B-Car variants, muffler vol is lower than class standard. System geometry overall is comparable with other vehicles in this class with the exception of the MB A-Class which has a single central muffler.

Appendix D4

FUCE Model for muffler system



VEHICLE	XXX		Front Box	Rear Box 1	Rear Box 2	Assy
CREATOR	Petros Souchoroukov	£	5.741	8.663	0.000	5.767
	Cost ZERO TIME (£)	44.31				
	MY ESTIMATE (£)	46.53				

Ass	Desc	Code	Flag	Mat Usag	Mat Rate	Man Level	LB Gp	Lab Mins	Lab	OH	Pieces	OH	Mat Cost	Lab Cos	OHD	Item Cos	Manuf C	Cost
1	0 Inlet			1	0.5								0.500					0.5
2	0 Inlet																	
	Part																	
	INSF	1800060					AA	0	0.24	1	55	0		0	0.07	0.07	0.07	0.027
	END	7100230					AB	0	0.29	1	55	0		0	0.24	0.242	0.242	0.031
	END	7100230					AB	0	0.29	1	55	0		0	0.24	0.242	0.242	0.031
	CUT	7100010					AB	0	0.29	1	55	0		0	0.43	0.428	0.428	0.031
	AUT	7100130	D			1	AB	1.6	0.29	2	38	0		1.286	0	1.286	1.286	0.503
	CUT	7100030				1	AB	0.1	0.29	0	600	0		0.08	0.03	0.106	0.106	0.031
	S/S			0.15	0.594								0.089			17.732	17.732	0.0891
	SUB							1.7		6			0.089	1.366	1.01	21.046	21.046	0.745
3	0 Inter																	
	Part																	
	INSF	1800060					AA	0	0.24	1	55	0		0	0.07	0.07	0.07	0.027
	END	7100230					AB	0	0.29	1	55	0		0	0.24	0.242	0.242	0.031
	END	7100230					AB	0	0.29	1	55	0		0	0.24	0.242	0.242	0.031
	CUT	7100010					AB	0	0.29	1	55	0		0	0.43	0.428	0.428	0.031
	AUT	7100130	D			1	AB	1.6	0.29	2	38	0		1.286	0	1.286	1.286	0.503
	CUT	7100030				1	AB	0.1	0.29	0	600	0		0.08	0.03	0.106	0.106	0.031
	S/S			1.95	3								5.850			17.732	17.732	5.85
	SUB							1.7		6			5.850	1.366	1.01	21.046	21.046	6.506
4	0 TAIL																	
	Part																	
	INSF	1800060					AA	0	0.24	0	182	0		0	0.02	0.021	0.021	0.008
	END	7100250					AB	0	0.29	0	182	0		0	0.06	0.062	0.062	0.009
	TUB	7100010					AB	0	0.29	0	182	0		0	0.13	0.129	0.129	0.009
	TUB	7100010					AB	0	0.29	0	182	0		0	0.13	0.129	0.129	0.009
	AUT	7100130	D			1	AB	0.33	0.29	0	182	0		0.265	0	0.265	0.265	0.104
	CUT	7100030				1	AB	0.1	0.29	0	600	0		0.08	0.03	0.106	0.106	0.031
	S/S			1.6	3								4.800			1.761	1.761	4.800
	SUB							0.43		2			1.761	0.346	0.56	2.666	2.666	4.972
5	0 SUB																	
	Part																	
	HAN	1900080					AB	0.65	0.29	1	92	0		0.174	0.11	0.281	0.281	0.204

			MIG	1000060				1	AB	0.65	0.29	1	92	0		0.523	0.05	0.567	0.567	0.204
			SIZE	7100230				1	AB	0.1	0.29	0	600	0		0.08	0.02	0.102	0.102	0.031
			SUB							1.4		1			0.000	0.777	0.17	0.951	0.951	0.440
	6	0	END																	
			Part																	
			INSF	1800060					AA	0	0.24	0	600	0		0	0.01	0.006	0.006	0.002
			PRO	6100130				1	AB	0.1	0.29	0	600	0		0.08	0.03	0.105	0.105	0.031
			WINI	6500220					AA	0	0.24	0	600	0		0	0.03	0.028	0.028	0.002
			Fron		EACH	0.31	1.5								0.471			2.264	2.264	0.942
			SUB							0.1		0			0.471	0.08	0.06	2.403	2.403	0.979
																				1.958
	7	0	PER																	
			Part																	
			INSF	1800060					AA	0	0.24	0	200	0		0	0.02	0.019	0.019	0.007
			RED	7100250				1	AB	0.2	0.29	0	300	0		0.161	0.04	0.198	0.198	0.063
			MIG/	1000340					AB	0.3	0.29	0	200	0		0.08	0.05	0.126	0.126	0.094
			ROB	1000060					AB	0	0.29	0	200	0		0	0.02	0.021	0.021	0.009
			AUT	7100180	D			0.5	AB	0.15	0.29	0	200	0		0.121	0	0.121	0.121	0.0515
			INSF	1800060				1	AA	0.1	0.24	0	600	0		0.077	0.01	0.083	0.083	0.027
			PRO	6100110				1	AB	0.15	0.29	0	400	0		0.121	0.03	0.153	0.153	0.047
			WINI	6500220					AA	0	0.24	0	600	0		0	0.03	0.028	0.028	0.002
Front Muffler			PER			0.358	0.594								0.213			1.976	1.976	0.213
			SUB							0.9		2			0.213	0.559	0.38	2.915	2.915	0.514
5.741																				
	8	0	PER																	
			Part																	
			INSF	1800060					AA	0	0.24	0	200	0		0	0.02	0.019	0.019	0.007
			RED	7100250				1	AB	0.2	0.29	0	300	0		0.161	0.04	0.198	0.198	0.063
			MIG/	1000340					AB	0.3	0.29	0	200	0		0.08	0.05	0.126	0.126	0.094
			ROB	1000060					AB	0	0.29	0	200	0		0	0.02	0.021	0.021	0.009
			AUT	7100180				0.5	AB	0.15	0.29	0	200	0		0.121	0.18	0.298	0.298	0.051
			INSF	1800060				1	AA	0.1	0.24	0	600	0		0.077	0.01	0.083	0.083	0.027
			PRO	6100110				1	AB	0.15	0.29	0	400	0		0.121	0.03	0.153	0.153	0.047
			WINI	6500220					AA	0	0.24	0	600	0		0	0.03	0.028	0.028	0.002
			PER			0.358	0.594								0.213			1.798	1.798	0.213
			SUB							0.9		2			0.213	0.559	0.37	2.724	2.724	0.514
	9	0	PER																	
			Part																	
			INSF	1800060					AA	0	0.24	0	200	0		0	0.02	0.019	0.019	0.007
			RED	7100250				1	AB	0.2	0.29	0	300	0		0.161	0.04	0.198	0.198	0.063
			MIG/	1000340					AB	0.3	0.29	0	200	0		0.08	0.05	0.126	0.126	0.094
			ROB	1000060					AB	0	0.29	0	200	0		0	0.02	0.021	0.021	0.009
			AUT	7100180				0.5	AB	0.15	0.29	0	200	0		0.121	0.18	0.298	0.298	0.051
			INSF	1800060				1	AA	0.1	0.24	0	600	0		0.077	0.01	0.083	0.083	0.027
			PRO	6100110				1	AB	0.15	0.29	0	400	0		0.121	0.03	0.153	0.153	0.047
			WINI	6500220					AA	0	0.24	0	600	0		0	0.03	0.028	0.028	0.002
			PER			0.358	0.594								0.213			1.798	1.798	0.213
			SUB							0.9		2			0.213	0.559	0.37	2.724	2.724	0.514

	10	0	FRO																
			Part																
			SPO	1000170				AB	0	0.29	0	600	0		0	0.04	0.04	0.04	0.003
			GUIL	7000010			1	AB	0.1	0.29	0	600	0		0.08	0.01	0.092	0.092	0.031
			WINI	6500220				AA	0	0.24	0	600	0		0	0.03	0.028	0.028	0.002
			OUT		0.180	1.5								0.270			-0.093		0.270
			Innei		0.180	1.5								0.270			3.654	3.654	0.270
			SUB						0.1		0			3.561	0.08	0.08	3.721	3.721	0.576
	11	0	MUF																
			Part																
			INSF	1800060				AA	0	0.24	1	120	0		0	0.03	0.032	0.032	0
			END	7100230				AB	0	0.29	1	120	0		0	0.11	0.11	0.11	0
			LOC	1300070				AB	0	0.29	1	120	0		0	0.38	0.376	0.376	0
			PRE	1300050				AB	0	0.29	1	120	0		0	0.25	0.25	0.25	0
			FLAI	1300050				AB	0	0.29	1	120	0		0	0.25	0.25	0.25	0
			FOR	1300050			2	AB	1	0.29	1	120	0		0.804	0.25	1.054	1.054	0
			SUB		1	1.666			1		4			0.000	0.804	1.92	2.72	2.72	1.666
	12	0	REA																
			Part																
			SPO	1000170				AB	0	0.29	0	600	0		0	0.04	0.04	0.04	0.003
			GUIL	7000010			1	AB	0.1	0.29	0	600	0		0.08	0.01	0.092	0.092	0.031
			WINI	6500220				AA	0	0.24	0	600	0		0	0.03	0.028	0.028	0.00
			OUT		0.225	1.5								0.337			-0.093		0.337
			Innei		0.225	1.5								0.337			3.654	3.654	0.337
			SUB						0.1		0			3.561	0.08	0.08	3.721	3.721	0.711
	13	0	FRO																
			Part																
			INSF	1800060				AA	0	0.24	0	600	0		0	0.01	0.006	0.006	0.002
			HIGI	5800040			1	AB	0.1	0.29	0	600	0		0.08	0.22	0.299	0.299	0.031
			DBL	6500210				AA	0	0.24	0	600	0		0	0.02	0.02	0.02	0.002
			STAI		3.14	0.594								1.866			2.096	2.096	1.866
			SUB						0.1		0			1.866	0.08	0.25	2.422	2.422	1.902
	14	0	REA																
			Part																
			INSF	1800060				AA	0	0.24	0	600	0		0	0.01	0.006	0.006	0.002
			HIGI	5800040			1	AB	0.1	0.29	0	600	0		0.08	0.22	0.299	0.299	0.031
			DBL	6500210				AA	0	0.24	0	600	0		0	0.02	0.02	0.02	0.002
			STAI		3.14	0.594								1.866			2.096	2.096	1.866
			SUB						0.1		0			1.866	0.08	0.25	2.422	2.422	1.902
	15	0	PLAI																
Rear Muffler 1			Part																
			INSF	1800060				AA	0	0.24	0	200	0		0	0.02	0.019	0.019	0.007
8.663			END	7100230			1	AB	0.3	0.29	0	200	0		0.241	0.07	0.307	0.307	0.094
			END	7100250				AB	0	0.29	0	200	0		0	0.06	0.057	0.057	0.009
			CUT	7100030			1	AB	0.1	0.29	0	600	0		0.08	0.03	0.106	0.106	0.031

		S/S '			0.255	1.83								0.467			1.403	1.403	0.467
		SUB							0.4		1			1.403	0.322	0.17	1.891	1.891	0.608
16	0	REA																	
		Part																	
		INSF	1800060					AA	0	0.24	1	43	0		0	0.09	0.089	0.089	0.034
		MIG	1000060				1	AB	0.25	0.29	0	240	0		0.201	0.02	0.218	0.218	0.079
		INDE	800540					AB	0	0.29	1	43	0		0	0.2	0.195	0.195	0.040
		ROB	1000060					AB	0	0.29	1	50	0		0	0.08	0.082	0.082	0.034
		MIG/	1000340					AB	1.4	0.29	1	43	0		0.375	0.21	0.586	0.586	0.440
		ASSI	800200				1	AB	1.4	0.29	1	43	0		1.125	0.06	1.182	1.182	0.440
		SUB							3.05		7			0.000	1.702	0.65	2.353	2.353	1.068
17	0	REA																	
		Part																	
		SPO	1000170					AB	0	0.29	0	600	0		0	0.04	0.04	0.04	0.003
		GUIL	7000010				1	AB	0.1	0.29	0	600	0		0.08	0.01	0.092	0.092	0.031
		DBL	6500220					AA	0	0.24	0	600	0		0	0.03	0.028	0.028	0.002
		INNE			0.225	1.5								0.337			3.738	3.738	0.337
		S/S :			0.225	1.5								0.337			-0.194		0.337
		SUB							0.1		0			3.544	0.08	0.08	3.703	3.703	0.711
18	0	REA																	
		Part																	
		INSF	1800060					AA	0	0.24	1	100	0		0	0.04	0.038	0.038	0.015
		SIZE	7100230					AB	0	0.29	1	100	0		0	0.13	0.132	0.132	0.017
		LOC	1300070				1	AB	0.6	0.29	1	100	0		0.482	0.45	0.934	0.934	0.189
		PRE	1300050					AB	0	0.29	1	100	0		0	0.3	0.3	0.3	0.017
		HYD	1300050	D				AB	0	0.29	1	100	0		0	0	0	0	0.017
		FLAI	1300050					AB	0	0.29	1	100	0		0	0.3	0.3	0.3	0.017
		FOR	1300050	D			3	AB	1.8	0.29	1	100	0		1.447	0	1.447	1.447	0.532
		SUB							2.4		4			0.000	1.929	2.05	3.977	3.977	0.804
19	0	SUB																	
		Part																	
		INSF	1800060					AA	0	0.24	1	43	0		0	0.09	0.089	0.089	0.034
		WEL	1000070	D				AB	0	0.29	1	43	0		0	0	0	0	0.040
		HAN	1900060	D				AB	1.4	0.29	1	43	0		0.375	0	0.375	0.375	0.440
		WEL	1000070	D			1	AB	1.4	0.29	1	43	0		1.125	0	1.125	1.125	0.440
		SUB							2.8		6			0.000	1.501	0.67	2.173	2.173	0.955
20	0	REA																	
		Part																	
		SPO	1000170					AB	0	0.29	0	600	0		0	0.04	0.04	0.04	0.003
		GUIL	7000010				1	AB	0.1	0.29	0	600	0		0.08	0.01	0.092	0.092	0.031
		WINI	6500220					AA	0	0.24	0	600	0		0	0.03	0.028	0.028	0.002
		OUT			0.000	1.5								0.000			-0.093		0.000
		Inner			0.000	1.5								0.000			3.654	3.654	0.000
		SUB							0.1		0			3.561	0.08	0.08	3.721	3.721	0.000

Rear Muffler 2

0.000

21	0	FRO																
		Part																
		INSF	1800060				AA	0	0.24	0	600	0		0	0.01	0.006	0.006	0.002
		HIGI	5800040			1	AB	0.1	0.29	0	600	0		0.08	0.22	0.299	0.299	0.031
		DBL	6500210				AA	0	0.24	0	600	0		0	0.02	0.02	0.02	0.002
		STAI		0.000	0.594								0.000			2.096	2.096	0.000
		SUB						0.1		0			0.000	0.08	0.25	2.422	2.422	0.000
22	0	REA																
		Part																
		INSF	1800060				AA	0	0.24	0	600	0		0	0.01	0.006	0.006	0.002
		HIGI	5800040			1	AB	0.1	0.29	0	600	0		0.08	0.22	0.299	0.299	0.031
		DBL	6500210				AA	0	0.24	0	600	0		0	0.02	0.02	0.02	0.002
		STAI		0.000	0.594								0.000			2.096	2.096	0.000
		SUB						0.1		0			0.000	0.08	0.25	2.422	2.422	0.000
23	0	PLAI																
		Part																
		INSF	1800060				AA	0	0.24	0	200	0		0	0.02	0.019	0.019	0.007
		END	7100230			1	AB	0.3	0.29	0	200	0		0.241	0.07	0.307	0.307	0.094
		END	7100250				AB	0	0.29	0	200	0		0	0.06	0.057	0.057	0.009
		CUT	7100030			1	AB	0.1	0.29	0	600	0		0.08	0.03	0.106	0.106	0.031
		S/S '		0.255	1.83								0.467			1.403	1.403	0.467
		SUB						0.4		1			1.403	0.322	0.17	1.891	1.891	0.000
24	0	REA																
		Part																
		INSF	1800060				AA	0	0.24	1	43	0		0	0.09	0.089	0.089	0.034
		MIG	1000060			1	AB	0.25	0.29	0	240	0		0.201	0.02	0.218	0.218	0.079
		INDE	800540				AB	0	0.29	1	43	0		0	0.2	0.195	0.195	0.040
		ROB	1000060				AB	0	0.29	1	50	0		0	0.08	0.082	0.082	0.034
		MIG/	1000340				AB	1.4	0.29	1	43	0		0.375	0.21	0.586	0.586	0.440
		ASSI	800200			1	AB	1.4	0.29	1	43	0		1.125	0.06	1.182	1.182	0.440
		SUB						3.05		7			0.000	1.702	0.65	2.353	2.353	0.000
25	0	REA																
		Part																
		SPO	1000170				AB	0	0.29	0	600	0		0	0.04	0.04	0.04	0.003
		GUIL	7000010			1	AB	0.1	0.29	0	600	0		0.08	0.01	0.092	0.092	0.031
		DBL	6500220				AA	0	0.24	0	600	0		0	0.03	0.028	0.028	0.002
		INNE		0.000	1.5								0.000			3.738	3.738	0.000
		S/S :		0.000	1.5								0.000			-0.194		0.000
		SUB						0.1		0			3.544	0.08	0.08	3.703	3.703	0.000
26	0	REA																
		Part																
		INSF	1800060				AA	0	0.24	1	100	0		0	0.04	0.038	0.038	0.015
		SIZE	7100230				AB	0	0.29	1	100	0		0	0.13	0.132	0.132	0.017
		LOC	1300070			1	AB	0.6	0.29	1	100	0		0.482	0.45	0.934	0.934	0.189

		PRE	1300050				AB	0	0.29	1	100	0		0	0.3	0.3	0.3	0.017
		HYD	1300050 D				AB	0	0.29	1	100	0		0	0	0	0	0.017
		FLAI	1300050				AB	0	0.29	1	100	0		0	0.3	0.3	0.3	0.017
		FOR	1300050 D			3	AB	1.8	0.29	1	100	0		1.447	0	1.447	1.447	0.532
		SUB						2.4		4			0.000	1.929	2.05	3.977	3.977	0.000
27	0	SUB																
		Part																
		INSF	1800060				AA	0	0.24	1	43	0		0	0.09	0.089	0.089	0.034
		WEL	1000070 D				AB	0	0.29	1	43	0		0	0	0	0	0.040
		HAN	1900060 D				AB	1.4	0.29	1	43	0		0.375	0	0.375	0.375	0.440
		WEL	1000070 D			1	AB	1.4	0.29	1	43	0		1.125	0	1.125	1.125	0.440
		SUB						2.8		6			0.000	1.501	0.67	2.173	2.173	0.000
28	0	FINA																
		Part																
		INSF	1800060				AA	0	0.24	2	25	0		0	0.15	0.153	0.153	0.058
		PRE	2100130 D			1	AC	2.4	0.33	2	25	0		0.7848	0	2.014	2.014	0.863
		WEL	1000340 D				AB	2.4	0.29	2	25	0		0.6864	0	0.643	0.643	0.755
		INDE	800540 D				AB	0	0.29	2	25	0		0	0	0	0	0.069
		HAN	1900060 D				AB	2.4	0.29	2	25	0		0.6864	0	0.643	0.643	0.755
		SUB						7.2		12			0.000	3.3	2.05	5.348	5.348	2.500
29	0	LABI		1	0.033								0.033			0.1	0.1	0.033
30	0	WEL		1	0.27								0.270			0.8	0.8	0.270
31	0	HAN		0	0.292								0.000			0.875	0.875	1.000
32	0	HAN		2	0.58								1.160			1.75	1.75	1.160
33	0	HAN		1	0.46								0.460			1.4	1.4	0.460
34	0	E GL		1	1.03								1.033			2.733	2.733	1.033
35	0	STEI		1	0								0.000			1	1	1.000
36	0	FLE)		1	9.29								9.290			27.87	27.87	9.290

Engine Size	y = 418.72x-253.17 E-glass Weight	y = 3.8032x2 - 1.067x + 9.7821 Muffler Volume
3	1002.99	40.81

0.8	1	1.2
1.3	1.4	1.5
1.6	1.8	2
2.2	2.5	3

	ENGINE	Pipe Dia.	E-Glass Weight	Muffler Vol.
1	0.8	38	81.81	11.36
2	1	42	165.55	12.52
3	1.2	42	249.29	13.98
4	1.3	42	291.17	14.82
5	1.4	42	333.04	15.74
6	1.5	42	374.91	16.74
7	1.6	42	416.78	17.81
8	1.8	50	500.53	20.18
9	2	50	584.27	22.86
10	2.2	50	668.01	25.84
11	2.5	54	793.63	30.88
12	3	54	1002.99	40.81

	PERFOF	Material	Thickness	Rate/metre
1	1 year	Mild Steel		1.5
2	2-3 Year:	Al. M. Steel		1.5
3	4 Years	Med. Grd.Steel		1.2
4	5 Years	S/S		1

AESTHE	Material	Rate/metre
sport/luxı	Al.M. Steel	
family	ALUM	

CLASS	Inlet	Inter	Tail	Length of pipe		
A	0.30	1.00	0.15	2.0		1.45
B	0.15	1.95	0.20	2.3		2.30
C	0.20	1.65	0.15	2.0	In this case base costa are the same	2.00
C/D	0.25	1.85	0.20	2.3	Class C/D Have reinforcement pipe	2.30
D	0.25	2.05	0.30	2.6	Class C/d Have Tuning Tube	2.60

ENGINE SIZE		1	2 to 33	4	5
	0.8	0.89	1.89	2.89	3.89
	1	2	3	4	5
	1.2	3	4	5	6
	1.3	4	5	6	7
	1.4	5	6	7	8
	1.5	6	7	8	9
	1.6	7	8	9	10
	1.8	8	9	10	11
	2	9	10	11	12
	2.2	12	13	14	15
	2.5	12	13	14	15
	3	13	14	15	16

Country of Origin	TimeFrame
UK	1y
Mexico	2y
China	3y
India	4y

AESTH2	Tail pipe no
DOUBLE EXIT	2
SINGLE	1

###

###

Dia x Thickness	Cost/metre Mild Steel	Al.M. Steel	M.Grd.Steel	S/S	cr
39.5	0.89	0.534	0.356	1.78	1
39.2	0.72	0.432	0.288	1.44	1
39	0.72	0.432	0.288	1.44	1
43.5	0.99	0.594	0.396	1.98	11
43.2	0.795	0.477	0.318	1.59	1
43	0.795	0.477	0.318	1.59	1
51.5	1.185	0.711	0.474	2.37	1
51.2	0.955	0.573	0.382	1.91	1
51	0.795	0.477	0.318	1.59	11
55.5	1.28	0.768	0.512	2.56	1
55.2	1.03	0.618	0.412	2.06	1
55	0.865	0.519	0.346	1.73	1

###

###

ENGINE SIZE	Pipe Dia.	E-Glass Weight		Muffler Vol.
1	0.7	38	39.9	11.4
2	1	42	165.6	12.5
3	1.2	42	249.3	14.0
4	1.3	42	291.2	14.8
5	1.4	42	333.0	15.7
6	1.5	42	374.9	16.7
7	1.6	42	416.8	17.8
8	1.8	50	500.5	20.2
9	2.1	50	626.1	22.9
10	2.2	50	668.0	25.8
11	2.5	54	793.6	30.9
12	3	54	1003.0	40.8

rear muff rad	1
front muff rad	0.5
reA/FRON RATIO	2.5

CLASS	Inlet	Inter	Tail	Muffler limit	front Muffler limit
A	0.30	1.00	0.15	10.00	5.00
B	0.15	1.95	0.20	12.50	6.25
C	0.20	1.65	0.15	21.30	10.65
C/D	0.25	1.85	0.20	32.00	16.00
D	0.25	2.05	0.30	40.00	20.00

LABOUR RATES PER **MINUTE**

LOCATION	AA	AB	AC	AS
China	0.07	0.10	0.11	0.12
India	0.05	0.08	0.09	0.10
UK	0.24	0.29	0.33	0.34
Mexico	0.08	0.11	0.13	0.14

SERVICE LIFE	MATERIAL TYPE	MAT. THICKNESS
0	ghhghg	
1 year	Mild Steel	1.5

2-3 Years	Al. M. Steel	1.5
4 Years	M.Grd.Steel	1.2
5 Years	S/S	1

AESTH 1	TAIL PIPE MATERIAL
sport/luxury	Cr steel
family	Al. M. Steel

AESTH2	Tail pipe no
DOUBLE EXIT	2
SINGLE	1

MATERIAL TYPE	cost/m2
Mild Steel	1
Al. M. Steel	1.5
M.Grd.Steel	2
S/S	2.8

	Cost/metre					
Dia x Thickness	Mild Steel	Al.M. Steel	M.Grd.Steel	S/S	Cr steel	
39.5	0.89	0.534	0.356	1.78	3	38x1.5
39.2	0.72	0.432	0.288	1.44	3	38x1.2
39	0.72	0.432	0.288	1.44	3	38x1
43.5	0.99	0.594	0.396	1.98	3	42x1.5
43.2	0.795	0.477	0.318	1.59	3	42x1.2
43	0.795	0.477	0.318	1.59	3	42x1
51.5	1.185	0.711	0.474	2.37	3	50x1.5
51.2	0.955	0.573	0.382	1.91	3	50x1.2
51	0.795	0.477	0.318	1.59	3	50x1
55.5	1.28	0.768	0.512	2.56	3	54x1.5
55.2	1.03	0.618	0.412	2.06	3	54x1.2
55	0.865	0.519	0.346	1.73	3	54x1

duration	inflation		
1y		0.05	1.05
2y		0.06	1.113
3y		0.07	1.19091
4y		0.06	1.2623646
5y		0.05	1.32548283

duration	inflation factor
1y	1.05

Engine Size	Inlet Flange
0.8	1
1	1
1.2	1
1.3	1
1.4	1
1.5	1
1.6	1
1.8	2
2	2
2.2	2
2.5	2
3	2

Engine Size	Inlet Flange
1.4	1

	0
VOID	

engine sie	Pipe Dia.	E-Glass Weight	Muffler Vol.	muff no
1.4	42	333.0	15.7	2

E-Glass Cost
1.03

	1stmuf	2ndmuf	frontmuf	
1	15.742572	0	0	vol
2	11.24469429	0	4.497877714	surface plate (
3	6.559405	6.559405	2.623762	surface drum
				length

1stmuf	2ndmuf	frontmuf
11.24469429	0	4.497877714
3.14	0	0.785398163
22.48938857	0	17.99151086
3.579297358	0	5.726875773

Inlet	Inter	Tail
0.15	1.95	1.6

class	Inlet	Inter	Tail	Muffler limit	Front muffler limit
B	0.15	1.95	0.2	12.5	6.25

3 muf coef	1.5
double exit coef	
1	8
2	8
3	2

muf no	Inlet	Inter	Tail	
1	2.1	0	1.6	
2	0.15	1.95	1.6	
3	0.15	2.925	0.4	

AESTH 1	TAIL PIPE MATERIAL
sport/luxury	Cr steel

AESTH2	Tail pipe no
DOUBLE EXIT	2

Location	AA	AB	AC	AS
UK	0.24	0.29	0.33	0.34

LIFE	MAT. TYPE	MAT. THICK	cost/m2
2-3 Years	Al. M. Steel	1.5	1.5

PER **HOUR**

LOCATION	AA	AB	AC	AS
China	4.13	5.75	6.79	7.1
India	3	4.5	5.3	6
UK	14.55	17.16	19.62	20.18
Mexico	5	6.5	7.5	8.5

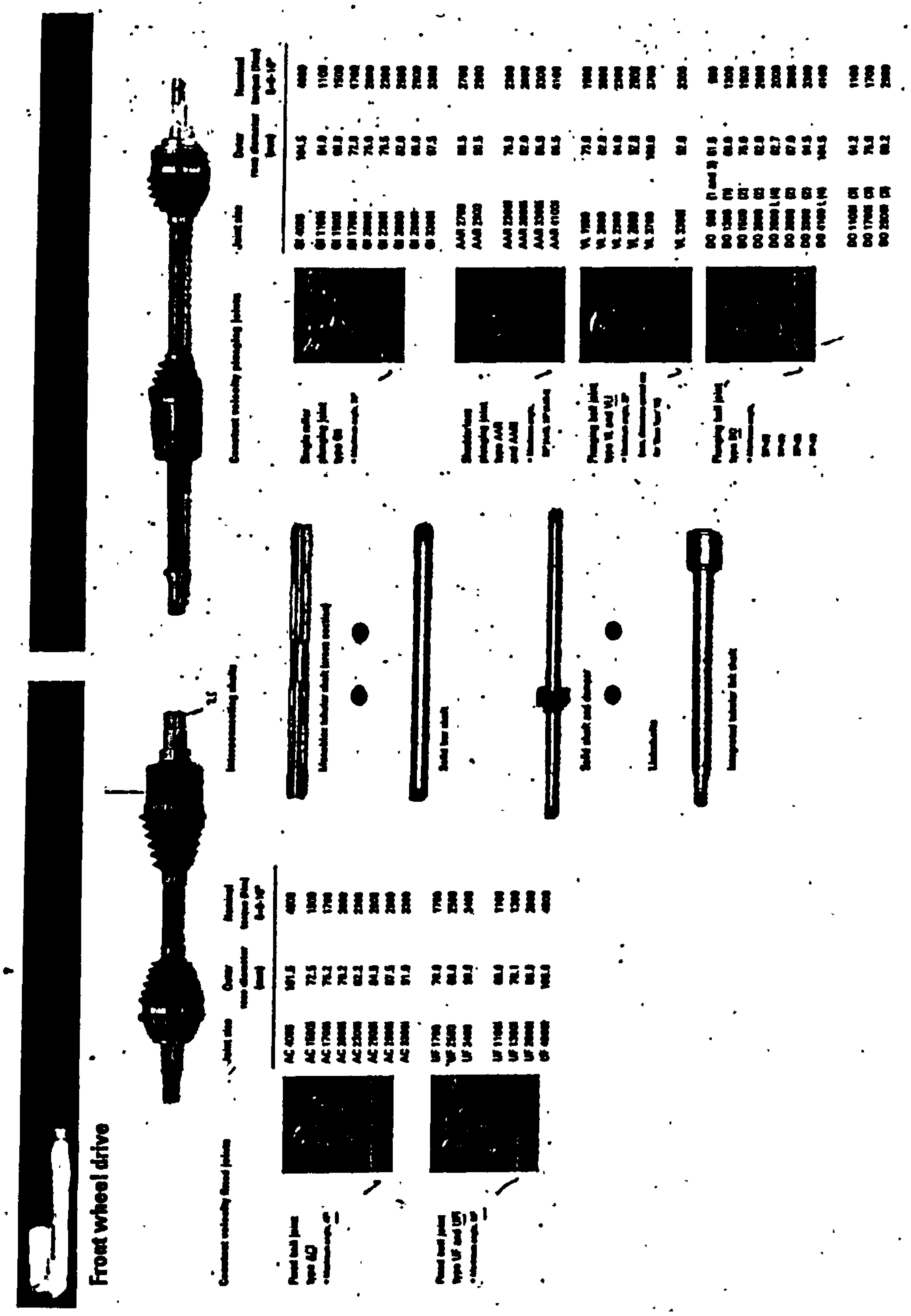
Country	AB	AC	AS
india	4.5		

cost/metre

pipemeasure	Mild Steel	Al. M. Steel	M.Grd.Steel	S/S	Cr steel		cost/meter
43.5	0.99	0.594	0.396	1.98		3 main	0.594
						tail	3

Appendix E1

List of Different Joints



Appendix E2
Sideshaft Estimate

Estimator [redacted]
Estimator Code [redacted]

[redacted]
#######

Lead Part No. Prefix Base Suffix
Handed Part No. [redacted] AD
Comparator Part No.
Part Description FRONT HALFSHAFT
Source Country Code/Supplier [redacted]

Release
TVM - REV CPSC Code #######
Buyer Code
Commodity C [redacted]
Master Part No
Vendor Shar 100

Key ID K
Comments REVISED FOLLOWING T5 INFORMATION

Part DPV 175

GBP
5

WORK IN PROGRESS ALIGNING US & EUROPE ESTIMATES
Totals:
Category
Defaults

	MF Scrap		SG&A		Profit		ED&T		Compo Total MU Value	
	####			7.50%	[redacted]		[redacted]		[redacted]	
	Appli %	Value	Applied %	Value	Applied %	Value	Applied %	Value	Applied %	
2nd Tier	[redacted]	[redacted]		[redacted]		[redacted]				
Material										
Labor										
Overhead										
BOM Item Markups										
Combined Totals										

Totals:
Source Currency GB 1st Ti 24 Manufacturing Cost 23 967 1st Tier Ma [redacted] Total Tool Cc 0
Economic Level 20(1st Ti 36.2 2nd Tier Content [redacted] Markup Ex [redacted] Total Piece C [redacted]

	Lev	No.	Assy	Description	Code	Flag	Mat Usage	Mat Rate	Man Lev	LB Gp	Lab Mins	Lab Rate	Pieces	Mat Cost	Lab Co	Item Cost	Manuf Cost Local		Compo Man. Cost
+	2	1	1	OUTBOARD JOINT FORGING - BELL															
+	2			Part Number: 1X43-3B437-AD															
+	2			817M40IM 820H17 / 40NICRMO6			1.343	0.577						0.852		0.852	0.852	GBP	0.852
+	2			BILLET SHEAR MAX BAR DIA: 125 M	5E+06				0.5	AB	0.016	0.2975	1824		0.005	0.015	0.015	GBP	0.015
+	2			INDUCTION BAR HEATER MAX BAR	5E+06				0.5	AB	0.056	0.2975	540		0.017	0.123	0.123	GBP	0.123
+	2			4 STATION 1600 TONNE WARM FOF	5E+06				3	CB	0.4	0.288	450		0.115	0.772	0.772	GBP	0.772
+	2			PHOSPHATE COAT	3E+06				1	AB	0.123	0.2975	487		0.037	0.149	0.149	GBP	0.149
+	2			COLD FORM	5E+06				1	CB	0.15	0.288	400		0.043	0.11	0.11	GBP	0.11
+	2			INSPECTION & PACK	2E+06				1	AB	0.092	0.2975	650		0.027	0.029	0.029	GBP	0.029
	2			SUB							0.838			0.852	0.244	2.049	2.049	GBP	2.049
+	2	2	0	OUTBOARD JOINT MACHINING - BE															
+	2			Part Number: A-026J-21323															
+	2			TURN COMPLETE - 2 AXIS CNC LAT	5E+06				1	AB	1.875	0.2975	32		0.558	0.809	0.809	GBP	0.809
+	2			CONVEYOR 7.6M X 2.2M	800290					AB	0.625	0.1056	96		0.066	0.095	0.095	GBP	0.095
+	2			MILL SLOT/DRILL - VMC	4E+06					AB	0	0.2975	96		0	0.094	0.094	GBP	0.094
+	2			ROLL SPLINE & THREAD	5E+06					AB	0	0.2975	96		0	0.108	0.108	GBP	0.108
+	2			INDUCTION HARDENING (AXLE SH/	2E+06					AB	0	0.2975	96		0	0.157	0.157	GBP	0.157
+	2			CONVEYOR 7.6M X 2.2M	800290					AB	0.625	0.1056	96		0.066	0.095	0.095	GBP	0.095
+	2			ROLL MARKING	800490					AB	0	0.2975	96		0	0.01	0.01	GBP	0.01
+	2			TEMPERING FURNACE 1219 MM WI	2E+06					AB	0	0.2975	96		0	0.358	0.358	GBP	0.358

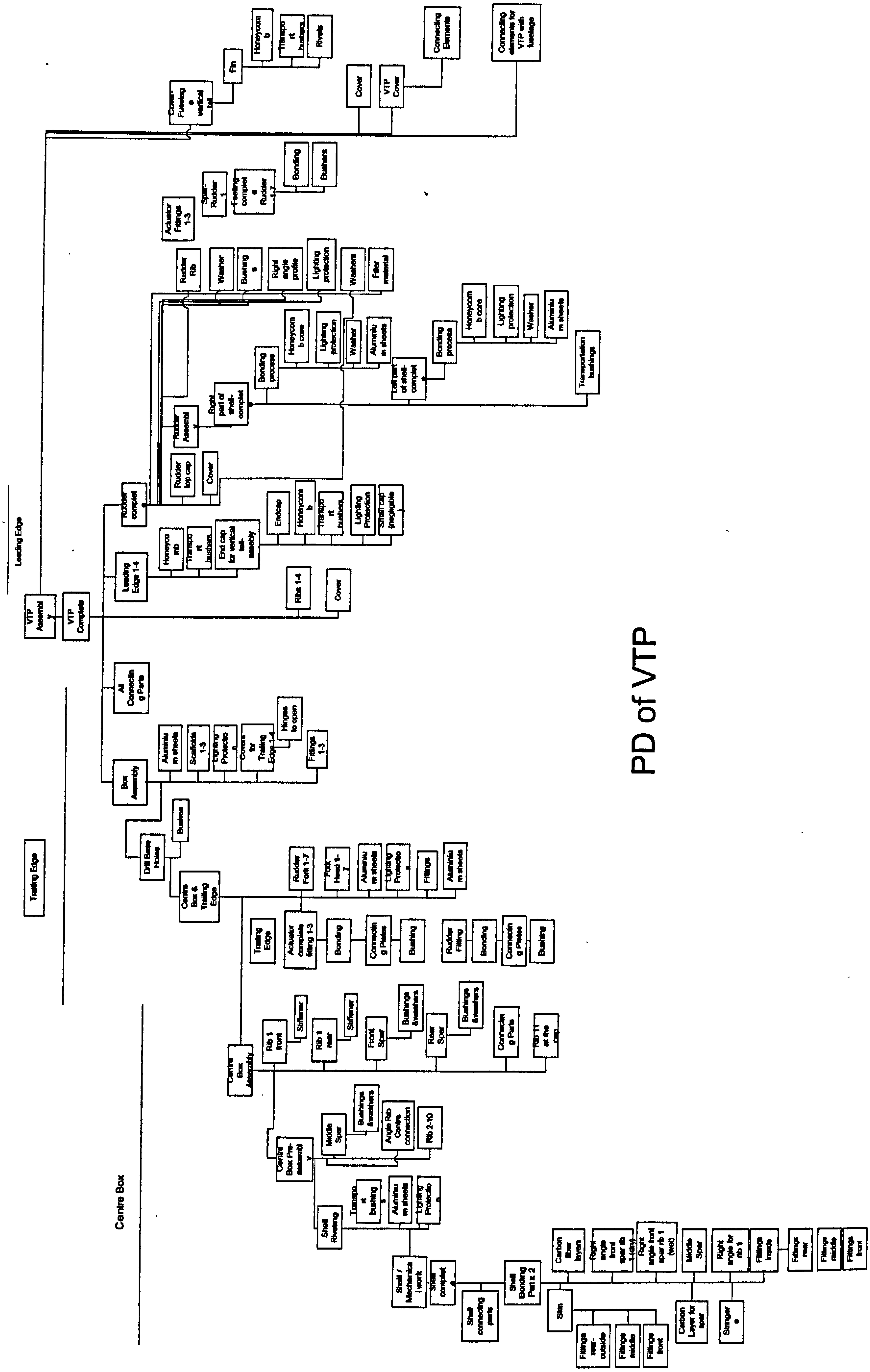
+	2		CONVEYOR 7.6M X 2.2M	800290			AB	0.625	0.1056	96		0.066	0.095	0.095 GBP	0.095
+	2		EDDY CURRENT TEST & SPLINE CH	2E+06			AA	0	0.2523	96		0	0.047	0.047 GBP	0.047
+	2		HARD TURN - 4 AXIS CNC LATHE	5E+06			1 AB	0.625	0.2975	96		0.186	0.325	0.325 GBP	0.325
+	2		2 SPINDLE CNC VERTICAL TURNIN(	5E+06 R			1 AB	0.625	0.2975	96		0.186	0 509	0.509 GBP	0.509
+	2		MAGNAFLUX INSPECTION	2E+06			2 AB	0.625	0.2975	192		0.186	0 209	0.209 GBP	0.209
	2		SUB					5 625			0	1.314	2.913	2.913 GBP	2.913
+	2	3	1 O/B JOINT CAGE - FORGING												
+	2		Part Number: GKN-227-0043												
+	2		530A36 530M40 / 37CRS4 41CR4		0.119	0.4853					0.116		0.116	0.116 GBP	0.116
+	2		SHEAR BLANK. 38 PPM X 60=2280	5E+06			1 CA	0.035	0.2506	1737		0.009	0.016	0.016 GBP	0.016
+	2		HEAT BILLET-INDUCTION FURNACE	5E+06			1 CB	0.126	0.288	476		0.036	0.053	0.053 GBP	0.053
+	2		FORGE-3 STROKES FORGE 3 STR	5E+06			1 CB	0.126	0.288	476		0.036	0.098	0.098 GBP	0.098
+	2		TRIM FLASH. LINE BALANCED TO I	5E+06			1 CB	0.28	0.288	214		0.081	0.099	0.099 GBP	0.099
+	2		NORMALIZE FORGING. LOAD APPI	2E+06			0.5 CB	0.073	0.288	410		0.021	0.054	0.054 GBP	0.054
+	2		SHOT BLAST. LINE BALANCED TO	2E+06			1 CB	0.073	0.288	819		0.021	0.043	0.043 GBP	0.043
+	2		PACK. PACKAGE IN CARDBOARD (	2E+06			1 CB	0.073	0.288	819		0.021	0.021	0.021 GBP	0.021
	2		SUB					0.786			0.116	0.225	0.5	0.5 GBP	0.5
+	2	4	1 O/B JOINT CAGE - MACHINING												
+	2		Part Number: GKN-227-0006												
+	2		TURN FACE BORE INDEX FACE COI	5E+06			0.5 AB	0 565	0.2975	53		0.168	0.388	0.388 GBP	0.388
+	2		PIERCE SIX WINDOWS-GEORG WIN	7E+06			0.5 AB	0.097	0.2975	309		0.029	0.096	0.096 GBP	0.096
+	2		BROACH SIX WINDOWS-FORST DU.	3E+06			0.5 AB	0.097	0.2975	309		0.029	0.058	0.058 GBP	0.058
+	2		WASH & INSPECT-CERA WASHER	2E+06			0.5 AB	0.075	0.2975	397		0.022	0.04	0.04 GBP	0.04
+	2		CARBURIZE-IPSEN BATCH FURNAC	2E+06			0.5 AB	0.07	0.2975	430		0.021	0.052	0.052 GBP	0.052
+	2		DRAW-IPSEN TEMPERING FURNAC	2E+06			0.5 AB	0.07	0.2975	430		0.021	0.07	0.07 GBP	0.07
+	2		GRIND SPHERICAL O.D.-BRYANT #L	3E+06			0.4 AB	0.255	0 2975	94		0.076	0.351	0.351 GBP	0.351
+	2		GRIND SPHERICAL I.D.-BRYANT #LI	3E+06			0.4 AB	0.255	0.2975	94		0.076	0.25	0.25 GBP	0.25
+	2		GRIND SIX WINDOWS-EXCELLO XG	3E+06			0.4 AB	0.179	0.2975	134		0.053	0.246	0.246 GBP	0.246
+	2		WASH-CERA WASH MACHINE-AUTC	2E+06			AB	0	0.2975	632		0	0.011	0.011 GBP	0.011
+	2		VIBRATORY DEBURR-ALMCO VIBR/	2E+06			1 AB	0.159	0.2975	377		0.047	0.052	0.052 GBP	0.052
+	2		WASH-CERA WASH MACHINE-AUTC	2E+06			AB	0	0.2975	632		0	0.011	0.011 GBP	0.011
	2		SUB					1.823			0	0.542	1.625	1.625 GBP	1.625
+	2	5	1 O/B JOINT INNER RACE FORGING												
+	2		Part Number: 1-225-0157-EXTR												
+	2		BS 040 060 080 120 212 220		0.184	0.4378					0.089		0.1	0.1 GBP	0.1
+	2		SHEAR BLANK: 38 PPM X 60=2280 F	5E+06			1 CA	0 033	0.2506	1824		0.008	0.017	0.017 GBP	0.017
+	2		ANNEAL BLANK:LOAD APPROX. 35(	2E+06			0.5 CB	0.07	0.288	430		0.02	0.058	0.058 GBP	0.058
+	2		PHOSPHATE COAT BLANK: .66 LB/P	3E+06			1 CB	0.033	0.288	1813		0.01	0.024	0.024 GBP	0.024
+	2		COLD FORM: 2 STROKES 500 TON I	5E+06			1 CB	0.178	0.288	337		0.051	0.156	0.156 GBP	0.156
+	2		ANNEAL BLANK	2E+06			0.5 CB	0.07	0.288	430		0.02	0.058	0.058 GBP	0.058
+	2		PHOSPHATE COAT BLANK	3E+06			1 CB	0.033	0.288	1813		0.01	0.024	0.024 GBP	0.024
+	2		FINISH COLD FORM:AUTOMATED L(	5E+06			1 CB	0.077	0.288	780		0.022	0.031	0.031 GBP	0.031
+	2		ISOTHERMAL ANNEAL & PACK	2E+06			1 CB	0.14	0.288	430		0.04	0.081	0.081 GBP	0.081
+	2		TURN FACE BORE INDEX FACE COI	5E+06			0.5 AB	0.4	0.2975	75		0.119	0.31	0.31 GBP	0.31
+	2		BROACH SPLINE-FORST DUAL RAM	3E+06			1 AB	0.098	0.2975	612		0.029	0.05	0.05 GBP	0.05
+	2		WASH & INSPECT. MACH.#2067 & #:	2E+06			1 AB	0.151	0.2975	397		0.045	0.071	0.071 GBP	0.071
+	2		CARBURIZE-IPSEN BATCH FURNAC	2E+06			0.5 AB	0.07	0.2975	430		0.021	0.059	0.059 GBP	0.059
+	2		DRAW-IPSEN TEMPERING FURNAC	2E+06			0.5 AB	0.07	0.2975	430		0.021	0.079	0.079 GBP	0.079
	2		SUB					1.421			0.089	0.416	1.117	1.117 GBP	1.117
+	2	6	0 PREMIUM STEERING FEEL FORGIN												
+	2		Part Number: 1X43-3B437-AD												
	2		PREMIUM STEERING FEEL FORGIN								0.5		0.5	0.5 GBP	0.5

	2		SUB					0			0.5	0	0.5	0.5 GBP	0.5
+	2	7	1 O/B JOINT INNER RACE MACHINING												
+	2		Part Number: 1-225-0157-MACH												
+	2		GRIND SPHERICAL O.D. BRYANT LE	3E+06			0.33 AB	0.093	0.2975	212		0.028	0.149	0.149 GBP	0.149
+	2		GRIND SIX ANGULAR BALL GROOVI	3E+06			0.33 AB	0.247	0.2975	80		0.074	0.397	0.397 GBP	0.397
+	2		WASH-CERA WASH MACHINE-AUTC	2E+06			AB	0	0.2975	1316		0	0.005	0.005 GBP	0.005
+	2		VIBRATORY DEBURR	2E+06			AB	0	0.2975	485		0	0.003	0.003 GBP	0.003
+	2		WASH-CERA WASH MACHINE-AUTC	2E+06			AB	0	0.2975	1316		0	0.005	0.005 GBP	0.005
+	2		FINAL INSPECT-BENCH 6580 PCS.N	2E+06			1 AB	0.073	0.2975	822		0.022	0.023	0.023 GBP	0.023
	2		SUB					0.414			0	0.123	0.583	0.583 GBP	0.583
	1	8	6 O/B JOINT STEEL BALL		1	0.05					0.05		0.05	0.3 GBP	0.3
+	2	9	1 INBOARD JOINT FORGING - TULIP F												
+	2		Part Number: 1X43-3B437-AD												
+	2		530A36 530M40 / 37CRS4 41CR4		1.08	0.4483					0.533		0.533	0.533 GBP	0.533
+	2		BILLET SHEAR MAX BAR DIA: 125 M	5E+06			0.5 AB	0.016	0.2975	1824		0.005	0.015	0.015 GBP	0.015
+	2		INDUCTION BAR HEATER MAX BAR	5E+06			0.5 AB	0.056	0.2975	540		0.017	0.123	0.123 GBP	0.123
+	2		4 STATION 1600 TONNE WARM FOF	5E+06			3 CB	0.4	0.288	450		0.115	0.772	0.772 GBP	0.772
+	2		PHOSPHATE COAT	3E+06			1 AB	0.123	0.2975	487		0.037	0.149	0.149 GBP	0.149
+	2		COLD FORM	5E+06			1 CB	0.15	0.288	400		0.043	0.11	0.11 GBP	0.11
+	2		INSPECTION & PACK	2E+06			1 AB	0.092	0.2975	650		0.027	0.029	0.029 GBP	0.029
	2		SUB					0.838			0.533	0.244	1.73	1.73 GBP	1.73
+	2	10	1 INBOARD JOINT MACHINING - TULIF												
+	2		Part Number: E-01703-107												
+	2		TURN COMPLETE - 2 AXIS CNC LAT	5E+06			1 AB	1.5	0.2975	40		0.446	0.647	0.647 GBP	0.647
+	2		CONVEYOR 7.6M X 2.2M	800290			AB	0.5	0.1056	120		0.053	0.076	0.076 GBP	0.076
+	2		DEBURR - 2 WHEEL GRINDER	3E+06			AB	0	0.2975	120		0	0.089	0.089 GBP	0.089
+	2		ROLL SPLINE	5E+06			AB	0	0.2975	120		0	0.087	0.087 GBP	0.087
+	2		3 STAGE FLAT BELT POWER WASH	2E+06			AB	0	0.2975	120		0	0.058	0.058 GBP	0.058
+	2		CONVEYOR 7.6M X 2.2M	800290			AB	0.5	0.1056	120		0.053	0.076	0.076 GBP	0.076
+	2		INDUCTION HARDENING (AXLE SHA	2E+06			AB	0	0.2975	120		0	0.126	0.126 GBP	0.126
+	2		CONVEYOR 7.6M X 2.2M	800290			AB	0.5	0.1056	120		0.053	0.076	0.076 GBP	0.076
+	2		CNC GRINDER - CIRCLIP GROOVE	3E+06			0.5 AB	0.25	0.2975	120		0.074	0.163	0.163 GBP	0.163
+	2		5 STAGE INDUSTRIAL PARTS WASH	2E+06			1 AB	0.5	0.2975	120		0.149	0.252	0.252 GBP	0.252
	2		SUB					3.75			0	0.828	1.651	1.651 GBP	1.651
+	2	11	90 NEEDLE - SPIDER ASSEMBLY												
+	2		Part Number: 1L2W-4K138-CB												
	2		NEEDLE - SPIDER ASSEMBLY								0.005		0.005	0.45 GBP	0.45
	2		SUB					0			0.005	0	0.005	0.45 GBP	0.45
+	2	12	3 RING RETAINING WASHER												
+	2		Part Number: 1L2W-4K138-CB												
	2		RING RETAINING WASHER								0.019		0.019	0.057 GBP	0.057
	2		SUB					0			0.019	0	0.019	0.057 GBP	0.057
+	2	13	3 SUPPORT WASHER												
+	2		Part Number: 1L2W-4K138-CB												
	2		SUPPORT WASHER								0.019		0.019	0.057 GBP	0.057
	2		SUB					0			0.019	0	0.019	0.057 GBP	0.057
+	2	14	3 BEARING ROLLER-SPIDER- OUTER												
+	2		Part Number: 1-235-0019-ROLLER												

+	2		817M40IM 820H17 / 40NICRMO6		0.036	0.5855					0.023		0.023	0.07 GBP	0.07
+	2		DRAW CUTOFF SLUG UPSET & EJE	5E+06			1 AB	0.02	0.2975	3000		0.006	0.017	0.052 GBP	0.052
+	2		HEAT TREAT 2000 LBS/HR .1 LB P/	2E+06			0.5 AB	0.002	0.2975	20000		0	0.002	0.006 GBP	0.006
+	2		QUENCH TEMPER & WASH. 2000 L	2E+06			0.5 AB	0.002	0.2975	20000		0	0.002	0.005 GBP	0.005
+	2		DOUBLE DISC GRIND BOTH FACES.	3E+06			0.5 AB	0.012	0.2975	2500		0.004	0.01	0.031 GBP	0.031
+	2		ROUGH GRIND SPHERICAL O.D.	3E+06			0.5 AB	0.05	0.2975	600		0.015	0.037	0.112 GBP	0.112
+	2		FINISH GRIND SPHERICAL O.D.	3E+06			0.5 AB	0 05	0.2975	600		0.015	0.037	0.112 GBP	0.112
+	2		GRIND ID	3E+06			0.5 AB	0.123	0.2975	244		0.037	0.086	0.259 GBP	0 259
+	2		WASH-BATCH 2000 LBS/HR .08 LB	2E+06			0.5 AB	0.001	0.2975	25000		0	0.001	0.002 GBP	0.002
+	2		TUMBLE TO LAP OD	2E+06			0.5 AB	0.05	0.2975	600		0.015	0.018	0.053 GBP	0.053
+	2		EDDY CURRENT CRACK DETECT 1(	2E+06			0.5 AB	0.025	0.2975	1200		0.007	0.009	0.028 GBP	0.028
+	2		INSPECT & PACK	2E+06			1 AB	0.05	0.2975	1200		0.015	0.016	0.047 GBP	0.047
	2		SUB					0.384			0.023	0.114	0.258	0.775 GBP	0.775
+	2	15	1 SPIDER FORGING												
+	2		Part Number: 1-235-0019-SPDR FOF												
+	2		530A36 530M40 / 37CRS4 41CR4		0.17	0.4853					0.091		0.091	0 091 GBP	0.091
+	2		SHEAR/COIL & SQUARE ENDS IN HI	5E+06			1 AB	0.02	0.2975	3000		0.006	0.025	0.025 GBP	0 025
+	2		STRESS RELIEVE 1800 LB LOAD .(	2E+06			0.25 AB	0.047	0.2975	317		0.014	0.057	0.057 GBP	0.057
+	2		PHOSPHATE COAT .63 LB/PC (REF :	3E+06			1 AB	0.033	0.2975	1823		0.01	0.021	0.021 GBP	0.021
+	2		PREFORM 500 TON FORGING PRES	5E+06			1 CB	0.06	0.288	1000		0.017	0.047	0 047 GBP	0.047
+	2		PHOSPHATE COAT .63 LB/PC (REF :	3E+06			1 AB	0.033	0.2975	1823		0.01	0.021	0.021 GBP	0.021
+	2		FINISH FORM 100 TON HYD PRESS	5E+06			1 CB	0.12	0.288	500		0.035	0.072	0.072 GBP	0.072
+	2		NORMALIZE 1000 LBS/HR	2E+06			1 AB	0.038	0.2975	1587		0.011	0.017	0.017 GBP	0.017
+	2		INSPECT	2E+06			1 AB	0.02	0.2975	3000		0.006	0.006	0.006 GBP	0.006
	2		SUB					0.371			0.091	0.109	0.357	0.357 GBP	0.357
+	2	16	1 SPIDER MACHINING												
+	2		Part Number: 1-235-0019-SPDRMAC												
+	2		FACE TURN & BORE. MACH.#2937 (	5E+06			0.5 AB	0.462	0.2975	65		0.137	0.317	0.317 GBP	0.317
+	2		TURN & GROOVE PEGS. OKUMA C.	5E+06			0.5 AB	0.462	0.2975	65		0.137	0.261	0.261 GBP	0.261
+	2		BROACH SPLINE-MACH #1263 #202	3E+06			0.5 AB	0.102	0.2975	294		0.03	0.061	0.061 GBP	0.061
+	2		WASH & INSPECT. MACH.#2067 & #	2E+06			1 AB	0.151	0.2975	397		0.045	0.063	0.063 GBP	0.063
+	2		CARBURIZE-IPSEN BATCH FURNAC	2E+06			0.25 AB	0.035	0.2975	430		0.01	0.042	0.042 GBP	0.042
+	2		DRAW-IPSEN TEMPERING FURNAC	2E+06			0.25 AB	0.035	0.2975	430		0.01	0.059	0.059 GBP	0.059
+	2		GRIND TRUNNIONS: GRIND SIMO T	3E+06			0.5 AB	0.375	0.2975	80		0.112	0.268	0.268 GBP	0.268
+	2		INSPECT	2E+06			1 AB	0.06	0 2975	1000		0.018	0.019	0.019 GBP	0.019
	2		SUB					1.681			0	0.5	1.089	1.089 GBP	1.089
+	2	17	1 SPIDER ASSY												
	2		SPIDER ASSY												
	2		[12] x03 RING RETAINING WASHER												
	2		[14] x03 BEARING ROLLER-SPIDER												
	2		[16] x01 SPIDER MACHINING												
	2		[13] x03 SUPPORT WASHER												
	2		[11] x90 NEEDLE - SPIDER ASSEMB												
	2		[10] x01 INBOARD JOINT MACHININ												
	2		[9] x01 INBOARD JOINT FORGING -												
	2		[15] x01 SPIDER FORGING												
+	2		ASSY. INSPECT RUST INHIB. & PAC	800600			1 AB	0.3	0.2975	200		0.089	0.176	0.176 GBP	0.176
	2		SUB					0.3			0	0.089	0.176	0.176 GBP	0.176
+	2	18	0 CONNECTING SHAFT												
+	2		Part Number: A-02629-119												
+	2		BAR STEEL CARBON		1.573	0 6226					1.077		1.077	1.077 GBP	1.077
+	2		FACE & CENTRE	5E+06			1 AB	0 667	0.2975	90		0.198	0.247	0.247 GBP	0.247

+	2		CONVEYOR 7.6M X 2.2M	800290			AB	0.667	0.1056	90		0.07	0.102	0.102 GBP	0.102
+	2		FINISH TURN BOTH ENDS	5E+06			AB	0	0.2975	45		0	0.259	0.259 GBP	0.259
+	2		AUTO GAUGING STATION	2E+06			AB	0	0.2975	90		0	0.035	0.035 GBP	0.035
+	2		ROLL SPLINE	5E+06			AB	0	0.2975	90		0	0.206	0.206 GBP	0.206
+	2		ROBOT-6 AXIS 12KG MX P/LD	2E+06			AB	0.667	0.1056	90		0.07	0.115	0.115 GBP	0.115
+	2		ROLL SPLINE	5E+06			AB	0	0.2975	90		0	0.206	0.206 GBP	0.206
+	2		CONVEYOR 7.6M X 2.2M	800290			AB	0.667	0.1056	90		0.07	0.102	0.102 GBP	0.102
+	2		INDUCTION HARDEN	2E+06			1 AB	0.667	0.2975	90		0.198	0.366	0.366 GBP	0.366
+	2		STRAIGHTEN & CRACK TEST - 2 MA	2E+06			0.5 AB	0.111	0.2975	270		0.033	0.049	0.049 GBP	0.049
	2		SUB					3.444			1 077	0 641	2.765	2.765 GBP	2.765
	1	19	1 OUTBOARD L/BOOT CLAMP		1	0.27					0.27		0.27	0.27 GBP	0.27
	1	20	1 OUTBOARD BOOT		1	1.247					1.247		1.247	1.247 GBP	1.247
	1	21	1 OUTBOARD S/BOOT CLAMP		1	0.176					0.176		0.176	0.176 GBP	0.176
	1	22	1 INBOARD L/BOOT CLAMP		1	0.27					0.27		0.27	0.27 GBP	0 27
	1	23	1 INBOARD BOOT		1	0.85					0.85		0.85	0.85 GBP	0.85
	1	24	1 INBOARD S/BOOT CLAMP		1	0.176					0.176		0.176	0.176 GBP	0 176
	1	25	1 DIFF CIRCLIP		1	0.05					0.05		0.05	0.05 GBP	0.05
	1	26	1 OUTBOARD JOINT GREASE		1	0.259					0.259		0.259	0.259 GBP	0.259
	1	27	0 INBOARD JOINT GREASE		1	0.389					0.389		0.389	0.389 GBP	0.389
	1	28	1 ID LABEL		1	0.08					0.08		0.08	0.08 GBP	0.08
+	2	29	0 HALFSHAFT ASSY												
	2		HALFSHAFT ASSY												
	2		[23] x01 INBOARD BOOT												
	2		[22] x01 INBOARD L/BOOT CLAMP												
	2		[21] x01 OUTBOARD S/BOOT CLAMI												
	2		[20] x01 OUTBOARD BOOT												
	2		[19] x01 OUTBOARD L/BOOT CLAMI												
	2		[8] x06 O/B JOINT STEEL BALL												
	2		[28] x01 ID LABEL												
	2		[26] x01 OUTBOARD JOINT GREASE												
	2		[7] x01 O/B JOINT INNER RACE MA												
	2		[24] x01 INBOARD S/BOOT CLAMP												
	2		[25] x01 DIFF CIRCLIP												
	2		[5] x01 O/B JOINT INNER RACE FOI												
	2		[4] x01 O/B JOINT CAGE - MACHINI												
	2		[3] x01 O/B JOINT CAGE - FORGINC												
	2		[1] x01 OUTBOARD JOINT FORGINC												
	2		[17] x01 SPIDER ASSY												
+	2		ASSY CELL	800260 R			5 AB	3	0.2975	100		0.893	1.508	1 508 GBP	1.508
	2		SUB					3			0	0.893	1.508	1.508 GBP	1.508

APPENDIX E3



PD of VTP

Appendix E4

Parametric estimating template for VTP

Component	Serial No	Part Num.	Weight	Hours	Labour	Material	Sum
			in KG		in Euro	in Euro	in Euro
Leading Edge 1	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Leading Edge 2	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Leading Edge 3	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Leading Edge 4	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Fin	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Fin Tip	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
SLW-Rumpfanschluss	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
VTP Panels front	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
VTP Panels front	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
VTP Panels middle	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
VTP Panels middle	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
VTP Panels rear	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
VTP Panels rear	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Sum	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Trailing Edge 1L	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Trailing Edge 2L	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Trailing Edge 3L	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Trailing Edge 4L	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Trailing Edge 5L	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Trailing Edge 1R	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Trailing Edge 2R	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Trailing Edge 3R	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Trailing Edge 4R	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Trailing Edge 5R	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Sum	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Shell Complete LH	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Shell Complete RH	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Shell Riveting LH	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Shell Riveting RH	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Middle Spar Assy	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Rib 2 Comlete	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Rib 3 front Plate	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Rib 4 Complete	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Rib 5 Complete	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Rib 6 Complet	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Rib 7 Complete	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Rib 8 Complete	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Rib 9 part	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Rib 10 part	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Rib 11 part	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Rib 12 part	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Rib 3 back plate	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
BoxAssembly	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
System	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Hydraulic Pipes	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Vertical fittings Front Spar	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Front Spar component	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Vertical Fittings Rear Spar H	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Rear Spar component	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Rib 1 front Plate	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Rib 1 rear Plate	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Rib 13 component	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Sum	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Fitting Complete BR1	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					

Fitting BR1	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Fitting Complete BR2/BR5	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Fitting BR2/BR5	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Fitting Complete BR3/BR4	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Fitting BR3/BR4	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Fitting Complete BR7/BR8	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Fitting BR7/BR8	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Fitting Complete BR6	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Fitting BR6	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Bushings	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Sum	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Actuator Fittings AC1 Comp	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Fitting AC1	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Bushers	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Actuator Fittings AC2 Comp	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Fitting AC2	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Bushers	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Actuator Fittings AC3 Comp	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Actuator AC3 under	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Bushers	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Sum	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Rudder fittings BR1(For Fitti	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Rudder fittings BR2	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Rudder fittings BR3	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Rudder fittings BR4	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Rudder fittings BR5	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Rudder fittings BR6	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Rudder fittings BR7	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Rudder fittings BR8A	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Sum	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Anbau Antenna Holder	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Fin tips rib	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Versteifungswinkel (Harden	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Trailing Edge spar (ER1 - B	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Trailing Edge spar (BR5 - B	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Trailing Edge spar (BR6 - V	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Trailing Edge spar (VFS - B	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Trailing Edge spar (BR7 - B	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Plate	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Fittings Complete	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Fittings	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Trägerplatte Complete	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Angles FS	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Small parts carbon fibre	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Sum	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Total Sum	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Rudder Spar	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Ruderl.Beschl.1(K=complet	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Rudder Fittings 1K	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Ruderl.Beschl.2K	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Ruderl.Beschl.3K	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Ruderl.Beschl.4K	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					
Ruderl.Beschl.5K	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx					

Ruderl.Beschl.6K	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
Ruderl.Beschl.7K	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
Ruderl.Beschl.7K	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
Ruderl.Beschl.8K	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
Ruderl.Beschl.8K	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
Actuators Fittings 1K	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
Akt.Beschlag 2K	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
Akt.Beschlag 3K	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
Rib under Component	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
RNR 0 =Rudder-nose-rib	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
RNR 1	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
RNR 2	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
RNR 3	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
RNR 4	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
RNR 5	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
RNR 6	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
RNR 7	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
RNR 8	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
RNR 9	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
RNR 10	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
RNR 11	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
RNR 12	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
RNR 13	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
RNR 14	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
RNR 15	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
RNR 16	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
RNR 17	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
RNR 18	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
RNR 19	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
RNR 20	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
RNR 21	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
RNR 22	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
Rudder nose 1LH	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
Rudernasenteil 1RH	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
Rudernasenteil 5/1LH	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
Rudernasenteil 2RH	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
Rudernasenteil 3LH	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
Rudernasenteil 3RH	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
Rudernasenteil 4LH	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
Rudernasenteil 4RH	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
Rudernasenteil 5/3LH	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
Rudernasenteil 5RH	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
Rudder Tip Complete	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
Rudder shells left and right	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
Sum Rudder	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
Rudder Assembly	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				
Rudder Complete	xxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxx				

Bought out Parts							

[redacted]uro

M

Appendix E5

Template to Derive Parametric Data

		Plane1			Plane 2	Plane 3	Plane 4			Plane 5			Plane 6	Plane 7		
Area	qm		22		24	45		45			53		51		53	
Height	m		5.9		6.7	8.3		8.3			9.3		8.8		9.3	
weight	kg		470		530	1,180		1,180			1,440		1,550		1,440	
Main Component		kg	€	€/kg			kg	€	€/kg	kg	€	€/kg		kg	€	€/kg
VTP Total		470	0	0	530	1180.2				1,608	618,252	384.00	684	2,650		
VTP Box		221	0		273	540	0	0		676	381,773		684	759		
Shells (L&R)		***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Spars		***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Ribs		***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Fittings		***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
		***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
VTP-Fairing & Bolting		16			18	32.6				73	17,338			30		
LE Total		70			70	166.8				190	50,661			703		
LE Assembly		***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Nose 1		***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Nose 2		***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Nose 3		***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Nose 4		***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Finne		***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Endcap		***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Rib		***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
TE Total		60			61	166.8	0	0		163				330		
TE Assembly		***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
TE Cover		***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Forks		***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Frame		***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
AC Fittings		***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
		***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
		***	***	***	***	***	***	***	***	***	***	***	***	***	***	***

Rudder Total		**85**			**88**	**239**	**242**	**185,221**	**765.00**	**335**	**128,666**	**384.00**		**715**		
Assembly		***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Shells (L&R)		***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Spar		***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Ribs		***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Nose Ribs (0 -22)		***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Rudder Nose Fairing		***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Fittings		***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Ruder Tip		***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Systems		**18**			**20**	**35**				**171.257**	**39,814**			**113.3**		
Equipment (Kaufteile)																
Kaufteile		***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
Rohre aus Speyer		***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
SLW Total		***	***	***	***	***	***	***	***	***	***	***	***	***	***	***